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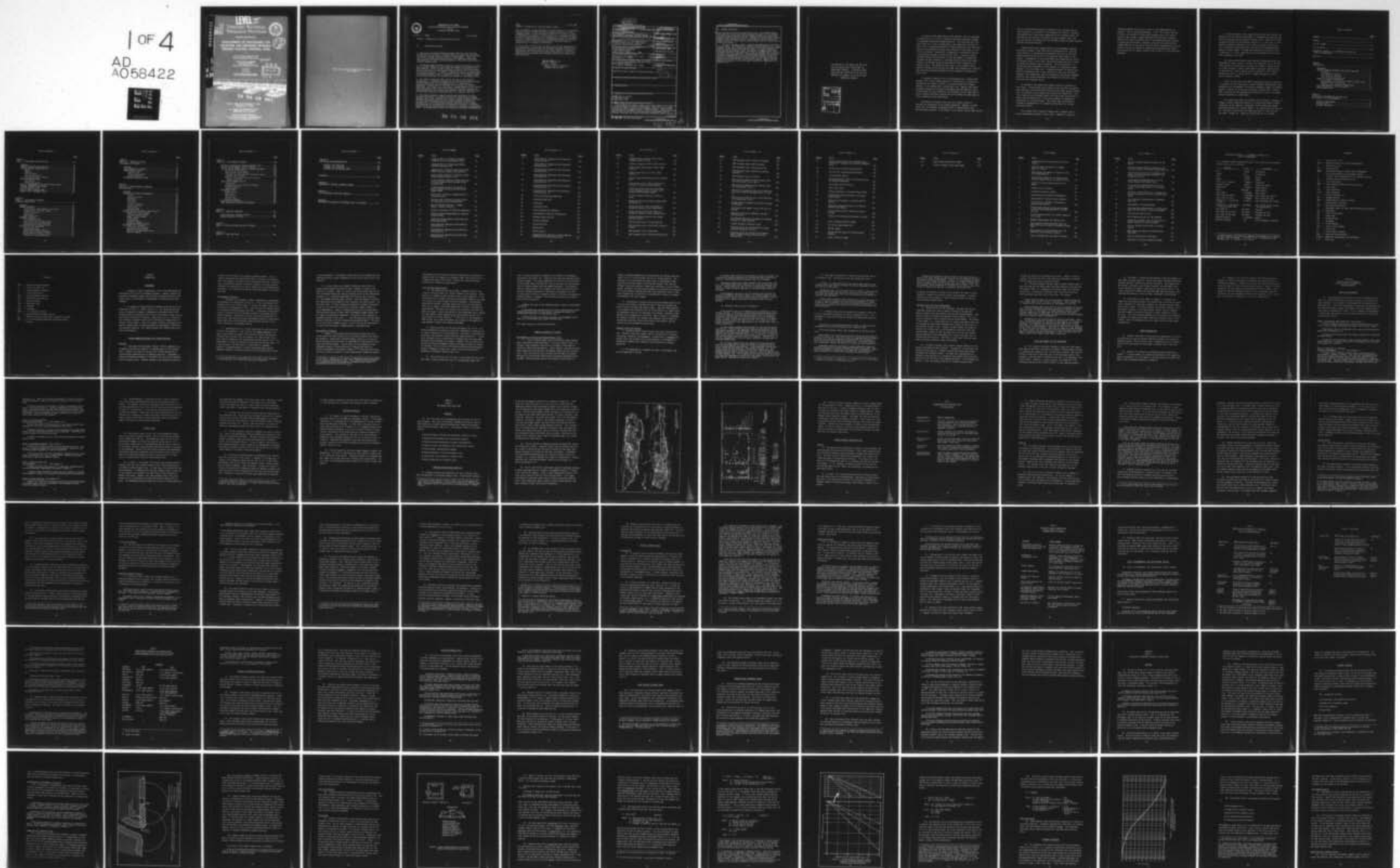

LEVEL II

DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-78-22

DEVELOPMENT OF PROCEDURES FOR SELECTING AND DESIGNING REUSABLE DREDGED MATERIAL DISPOSAL SITES

(12)
NW

by

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June 1978

Final Report

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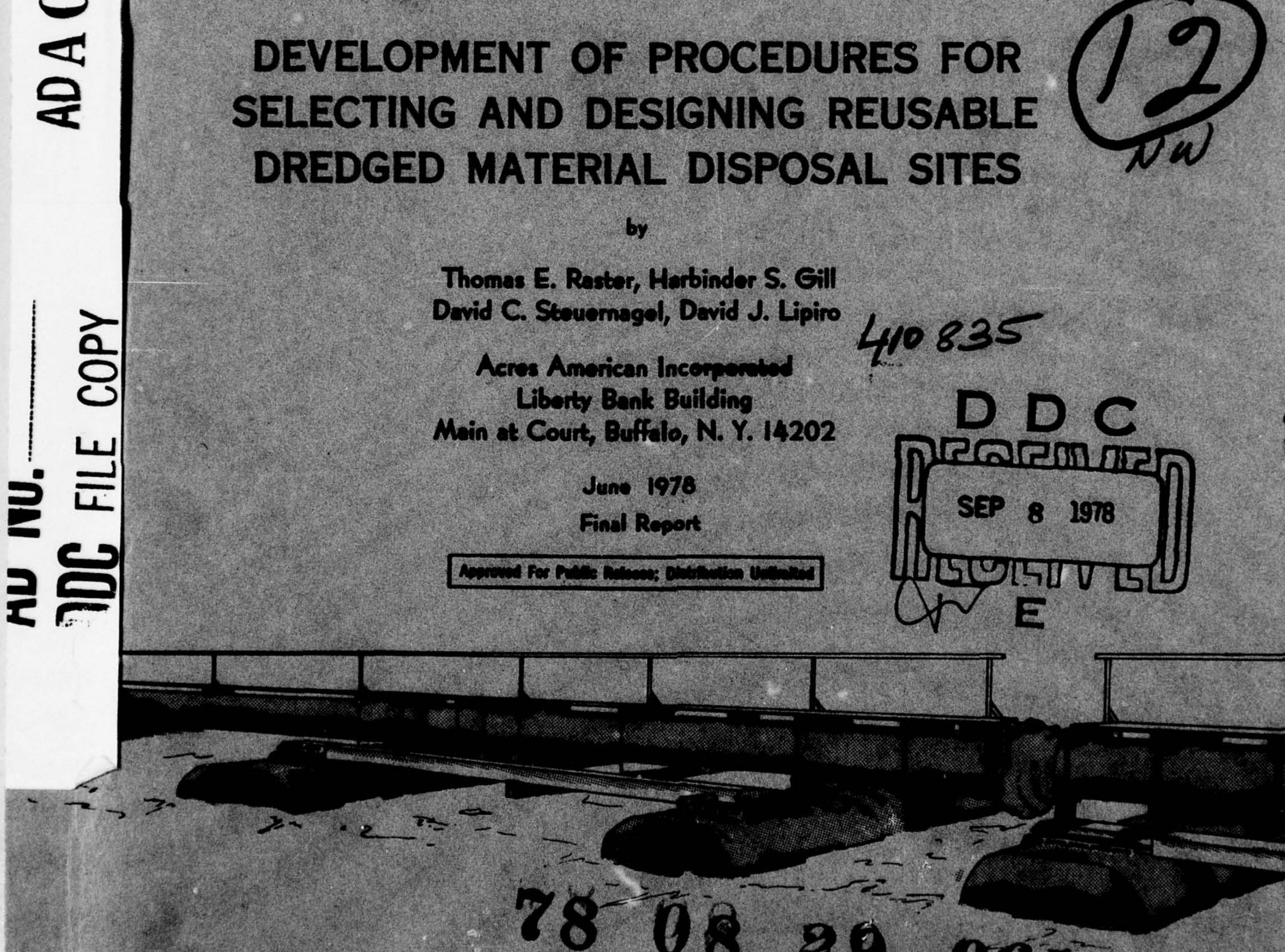

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SUBJECT: Transmittal of Technical Report D-78-22

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1. The report transmitted herewith presents results of one work unit initiated as part of Task 5C (Disposal Area Reuse Research) of the Corps of Engineers' Dredged Material Research Program (DMRP). Task 5C was part of the Disposal Operations Project of the DMRP and, among other considerations, included developing methods to extend the useful life of confined disposal areas.

2. Confining dredged material on land is a disposal alternative to which little specific design or construction improvement investigations have been addressed. There has been a dramatic increase in the last several years in the amount of land disposal necessitated in part by restrictions on open-water disposal. In order to minimize the amount of land required for confined disposal areas, a significant portion of the DMRP was aimed toward identifying ways of increasing the capacity of containment areas.

3. One concept considered under Task 5C was that of the reuseable disposal site. A reuseable disposal site is distinguished from a conventional disposal site in that dredged material is continuously or periodically removed from the reuseable site to retain its disposal capability. By definition of this report, dredged material is not removed from conventional sites. This study (Work Unit 5C05) was initiated to provide guidance on the selection and design of reuseable disposal sites. The study was conducted by Acres American, Inc., Buffalo, New York.

4. This report presents a logical step-by-step methodology for site selection and design. The method provides the capability for handling anything from a single disposal site serving a single dredging location to an entire dredging program involving several dredging locations and disposal sites. The methodologies identify pertinent factors (legal, environmental, and technological) that influence selection of candidate disposal sites and determine their suitability as reuseable or nonreuseable sites. The methodology includes site design and operating recommendations

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and a preliminary costing procedure to enable evaluation of alternative disposal options for each site and cost modifications of an entire dredging program. Numerous numerical examples are provided to assist in applying the procedures to a particular case. Although the report promotes reuseable disposal sites, management procedures for extending the life of nonreuseable sites of a conventional nature are also discussed in detail for those situations where reuseable sites are inappropriate or economically unfeasible.

5. The results of this study were used in part in the development of final guidelines for selecting and designing reuseable disposal sites. Consequently, guidelines given in this report should be considered interim with the final guidelines being forthcoming in a report that synthesizes and interprets work conducted under this and other work units in Task 5C.

JOHN L. CANNON
Colonel, Corps of Engineers
Commander and Director

(18) WES

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Environmental and economic concerns are providing impetus for an evolution in confined disposal site design and management. Some Districts are already experiencing economic pressures on their dredging programs. These pressures are generated by environmental factors--primarily changes in disposal procedures made necessary by legislation protecting surface and groundwater quality, wetlands, shorelines, etc.--and by inefficient conventional disposal practices

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which have used up most of the prime disposal sites. The reusable disposal site--boasting a long life and producing useful by-products--is the ultimate successor of the conventional site--too frequently short-lived, poorly engineered and operated, and failure-prone. Although this report promotes reusable disposal sites, nonreusable sites of a nonconventional nature are also discussed in detail for those situations where reusable sites are inappropriate or economically unsound.

This report presents a logical, step-by-step methodology for site selection and design. The methodology is capable of handling anything from a single disposal site serving a single dredging location to an entire dredging program involving several dredging locations and disposal sites. The methodology identifies pertinent factors--legal, environmental, and technological--which influence selection of candidate disposal sites and determine their suitability as reusable and nonreusable sites. The methodology presents site design and operating recommendations and a preliminary costing procedure to enable the District to evaluate alternative disposal options for each site and to cost modifications of the District's entire dredging program. Numerous numerical examples are provided to assist the reader in applying the procedures to his particular case.

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SUMMARY

A distinct trend toward more on-land disposal sites has developed in recent years as a result of questions regarding open-water disposal of suspected contaminated dredged materials. The increasing use of on-land sites has, in turn, brought about a rapid depletion of prime disposal sites, a problem aggravated by intense competition from other land uses and the designation of many areas, wetlands in particular, as off-limits to disposal. Reusability is proposed as a practicable solution to the growing shortage of prime disposal sites. A second, related challenge facing on-land disposal is the development of increasingly stringent effluent standards, a challenge that can be met with proper disposal site designs using the applicable effluent standard as the design criteria. The purpose of this report is to introduce the reusability concept and to provide the reader with procedures for selecting and executing preliminary designs and cost estimates of reusable disposal sites.

A "reusable" disposal site is distinguished from a "conventional" disposal site in that dredged material is continuously or periodically removed from the former to retain its disposal capability; dredged material is not removed from a conventional site. However, the design procedures related to achieving an acceptable effluent generally apply to both types of sites; therefore, the procedures in this report may be used to develop preliminary designs and cost estimates for both types of sites, permitting direct comparisons.

Traditionally, disposal sites have been located largely on the basis of convenience to the dredging operation. However, as these prime sites are depleted, convenience loses its preeminence in the decision-making process. As discussed in this report, several other factors

must be considered when selecting a disposal site, including many external factors (i.e., external to the disposal site itself), including the capabilities of the primary dredge and initial transport mode, the availability and locations of markets and waste disposal areas, and the availability of an egress-off-site transport system to handle possible products and waste materials.

Characteristically, dredged material from maintenance dredging activities includes a large fraction of fine-grained (silt- and clay-sized) material, an appreciable percentage of which can be colloidal particles which do not settle out of suspension under normal circumstances. Consequently, in most cases where the dredged material enters the disposal site in slurry form, unassisted gravity settling is unable to achieve the effluent quality required. The challenge then is to achieve the required degree of solids removal in a reasonably compact disposal site at a minimal cost. A noteworthy benefit of meeting standards for suspended solids is the resolution of most other pollutant problems since contaminants tend to be sorbed by fine-grained suspended particles; the sorbed contaminants are removed from the water column along with the suspended solids.

An economical two-stage solids removal process is presented in this report. (Single-stage solids removal using flocculants to agglomerate colloidal and near-colloidal particles into large, quickly settled flocs is possible, but was found to be economically impractical.) The first stage consists of normal gravity settling of most particulates to reach a solids concentration in the slurry amenable to inexpensive flocculation in the second stage. The second-stage flocculation is followed by sedimentation in a standard settling basin or in high-rate plate settlers.

The ultimate fate of material removed from a reusable site receives considerable attention in this report. Emphasis is given to

developing markets and uses for as much of the dredged material as possible. This is doubly advantageous: first, this reduces the magnitude of the problem of finding waste disposal areas for unwanted materials and, second, revenues generated from the sale of dredged material will partially offset costs of the dredging/disposal program. To expand possible markets, procedures are given for processing the dredged material to meet certain specifications; equipment and costs are shown for facilities capable of separating and beneficiating coarser-grained particles to produce anything from a clean fill to an ASTM Fine Aggregate.

PREFACE

The work described in this report was performed under Contract No. DACW39-75-C-0119, entitled "Development of Procedures for Selecting and Designing Reusable Dredged Material Disposal Sites," dated 30 June 1975, between Acres American Incorporated, Buffalo, N. Y., and the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi. This investigation constituted Work Unit 5C05 of the Dredged Material Research Program (DMRP). The DMRP was sponsored by the Office, Chief of Engineers, U. S. Army (DAEN-CWO-M), and was managed by the Environmental Laboratory (EL), WES.

The study was performed by Acres American Incorporated under the management of Messrs. David C. Willett, Vice President, and D. William Lamb, Manager of Transportation Division; Mr. Thomas E. Raster served as Project Engineer. Several staff members made major contributions, in particular Dr. John W. Hayden, Messrs. Harbinder S. Gill, David C. Steuernagle, David J. Lipiro, David L. Wright, and Gary E. Horvitz, and Mrs. Bonnie L. Mehls.

Credit must be given other DMRP investigators whose work provided a foundation for this study and to several equipment manufacturers whose cooperation was instrumental in developing workable concepts for dredged material recovery and processing at reusable disposal sites. Helpful DMRP investigations and equipment manufacturers are cited in the References and Appendix B, respectively.

The contract was under the direction of Mr. Charles C. Calhoun, Jr., Manager, Disposal Operations Project, EL, Contracting Officer's Representative, and Mr. Raymond L. Montgomery, Chief, Design and Concept Development Branch, EL, Contract Manager. Dr. John Harrison was Chief of EL. Directors of WES during the study were COL G. H. Hilt, CE, and COL John L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
mils	0.0254	millimetres
inches	25.4	millimetres
feet	0.3048	metres
yards	0.9144	metres
miles (U. S. statute)	1.609344	kilometres
feet per second	0.3048	metres per second
square feet	0.092903	square metres
acres	4046.856	square metres
cubic yards	0.7645548	cubic metres
cubic feet per second	0.02831685	cubic metres per second
cubic yards per hour	0.7645548	cubic metres per hour
gallons (U. S. liquid) per minute	3.785412	cubic decimetres per minute
gallons (U. S. liquid) per minute per square foot	40.745853	cubic decimetres per minute per square metre
tons (2000 lb)	907.18474	kilograms
tons (2000 lb) per hour	907.18474	kilograms per hour
tons (2000 lb) per year	907.18474	kilograms per year
degrees (angular)	0.01745329	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

NOTATION

A	=	area, acres or ft^2
ASTM	=	American Society for Testing and Materials
B	=	bulk density, g/l
BF	=	bulking factor
BWQM	=	Pennsylvania Bureau of Water Quality Management
C	=	solids concentration by dry weight, percent
C_1	=	influent solids concentration by dry weight, percent
C_2	=	effluent solids concentration, g/l
cfs	=	cubic feet/second
CMSP	=	coarse material separation and processing
cy	=	cubic yards
cyh	=	cubic yards/hour
cy/yr	=	cubic yards/year
D	=	particle diameter, μm
DM	=	dredged material
DMRP	=	Dredged Material Research Program
DT	=	densification techniques
ENR	=	Engineering News Record
F	=	adjustment factor for ideal settling theory area equation
fps	=	feet/second
FSR	=	final solids removal
g/l	=	grams/liter
gpm	=	gallons/minute
hp	=	horsepower
I.D.	=	inside diameter
ISR	=	initial solids removal
lf	=	linear foot
M	=	slurry specific gravity
O&M	=	operation and maintenance
O,M,&R	=	operation, maintenance, and replacement
P.L.	=	Public Law

PWR	=	product and waste recovery
Q	=	flow rate, gpm or cfs
R	=	solids retention, percent
S	=	solids density, g/l
SCS	=	Soil Conservation Service
SDR	=	solids delivery rate, tph
SG	=	specific gravity
t/cy	=	tons/cubic yard
tph	=	tons/hour
tpy	=	tons/year
USGS	=	U. S. Geological Survey
V	=	percent solids by volume, percent
V_m	=	percent of slurry volume which is material, percent
WES	=	U. S. Army Engineer Waterways Experiment Station
μ	=	microns

CHAPTER 1
INTRODUCTION

BACKGROUND

1. Dredging is widely recognized as vital to the development and maintenance of our Nation's navigable waterways. However, questions of possible environmental impacts have recently surfaced particularly with regard to open-water disposal of contaminated or biologically-enriched sediment.

2. In response to these questions, Congress passed the River and Harbor Act of 1970, P.L. (Public Law) 91-611. This law authorized the Corps of Engineers to conduct a comprehensive nationwide study of DM (dredged material) characteristics, effects of dredging on water quality, and alternative methods of disposal. Accordingly, the U. S. Army Engineer Waterways Experiment Station (WES) developed the Dredged Material Research Program (DMRP). Under this program, numerous investigations of specific problem areas are being conducted by consultants, universities, and government agencies. This report presents the findings from one of these investigations.

FACTORS PROMOTING DISPOSAL SITE DESIGN EVOLUTION

Overview

3. A move away from open-water disposal of DM in response to environmental concerns has resulted in a growing need for land disposal sites. However, the supply of choice sites is being depleted by existing disposal operations and by competing land uses. Furthermore, a growing environmental awareness is precluding the use of many otherwise suitable disposal sites. Reusable disposal sites represent a practical

solution to this disposal site supply and demand problem. Also, in light of present-day and anticipated trends in disposal site development, the reusable site appears to be the logical successor to the old-style, conventional disposal site which frequently has been selected, designed, and operated more by rule of thumb than by sound engineering principles. Let us examine the factors promoting disposal site design evolution.

Environmental Pressures

4. Congress has responded to today's atmosphere of environmental enlightenment with legislation such as P.L. 91-190, the National Environmental Policy Act of 1969, and P.L. 92-500, the Federal Water Pollution Control Act Amendments of 1972. Such laws mark the eventual demise of traditional confined disposal practices. Traditional (conventional) sites are characteristically designed, located, and operated with expediency foremost. Convenience, minimal cost, ease of acquiring disposal rights, and long-term storage requirements generally receive more regard than settling effectiveness (hence effluent quality), reliability, aesthetics, and eventual end use.

5. Implementation of P.L. 92-500 (guidelines for which were published in the September 5, 1975, issue of the Federal Register) will have a major impact on disposal site selection, design, and operation. Effluent from a confined site, for example, will have to meet "such water quality standards as are appropriate and applicable by law."[1] This requirement will tend to complicate site designs and increase costs. If a settling basin's surface area* is insufficient for adequate removal of suspended material to satisfy designated water quality standards, measures to enhance settling such as flocculation will have

* For a given DM slurry, the proportion of the total solids retained in a settling basin is a function of the area of the basin.

to be incorporated. If pollutants in DM slurry are not removed with the settled particles, various treatments will have to be used to polish the effluent.*

6. To date, there are no Federal regulations specifically directed toward seepage from disposal areas. However, a trend in this direction is evident. Under P.L. 93-523, the Safe Drinking Water Act of 1974, designated States must develop programs to ensure that underground injection, i.e., subsurface emplacement of fluids by well injection, will not endanger drinking water sources.[2] With few changes in wording, this regulation could be made to cover leachates from ponding areas. On the State level, "in 1972, Pennsylvania adopted the toughest regulations in the U.S. for controlling pollution from waste lagoons, ponds, or other impoundments. Intent on safeguarding the purity of ground water, the Pennsylvania Bureau of Water Quality Management (BWQM) demands that all lagoons be absolutely impermeable. The design of any proposed impoundment anywhere in the state . . . with the exception of potable water ponds on farms must first be reviewed and approved by BWQM."[3] This type of law could have tremendous impact, in fact, could be the determinant, in locating and designing a dredged material containment area.

Dike Stability Concerns

7. Changes in dike design and construction brought about by a rising concern for dike stability will also affect disposal site design and operation. Conventional confined disposal sites have a history of poorly designed dikes often built of substandard on-site materials using cheap construction methods. Dike failures are not uncommon; and the consequent release of large quantities of slurry often results in serious environmental and aesthetic impacts.[4,5,6] Dike deficiencies are receiving increasing attention; a move toward proper engineering studies

* Pollution is defined in this report as contamination beyond acceptable limits (usually established by law). Thus, although total elimination of a contaminant may not be achievable, treatment should reduce its concentration below the "pollution" level.

and designs and use of better construction materials and practices is apparent. WES, for example, has assigned a DMRP study specifically to disposal area dikes with the goal of producing a report providing guidelines for design and construction.[7]

Loss of Prime Disposal Areas

8. The increasing scarcity of cheap, convenient land for new sites will provide impetus for further disposal site evolution. Three factors will combine to make suitable sites a scarce commodity. First, most prime land is already occupied by conventional disposal sites, many still active, but some already filled and abandoned. Unfortunately, conventional disposal sites make inefficient use of the land because they rely on natural, unassisted dewatering (in effect, drainage) and consolidation. Most DM is fine grained and, therefore, poor draining. Water can occupy a significant portion of the containment area's storage for years before natural dewatering and consolidation restore sufficient volume for further disposal.[8] If the site is to be relegated to some end use, years might pass before the strength of the material is great enough to support the intended development.

9. Second, wetlands are now being designated "off limits." P.L. 92-500 implementation guidelines state that "degradation or destruction of aquatic resources by filling operations in wetlands is considered the most severe environmental impact covered by these guidelines."[1] In the past, low market value and proximity to dredging activities have made wetlands prime candidates for disposal. However, this low market value primarily reflects development prospects and does not begin to account for wetlands' value in terms of fish and wildlife habitat and breeding grounds, floodwater storage areas, natural pollution assimilation mechanisms, groundwater recharge areas, etc.

10. Third, Districts will find that, in the competition for available lands, disposal operations start at a disadvantage--other land

uses, including residential, commercial, and industrial development, agriculture, recreation, etc., generally have much more economic and/or aesthetic appeal. This tough competition will tend to drive land costs up and further reduce availability, forcing the search for new disposal sites to radiate outward from the dredging operation. The transport needs of remote disposal sites, however, can affect the efficiency of the total dredging operation; at some point, the capability of the existing plant in terms of transport distance or ability to complete the dredging program is exceeded. At this point, the District has essentially three alternatives:

- Reduce the scope of the dredging program--likely an unacceptable alternative.
- Seek additional appropriations for new or improved plant--which undoubtedly would entail a large capital investment and might also increase O&M (operation and maintenance) costs.
- Modify disposal site design, operation, and management--which might also involve additional capital and O&M costs.

This report focuses on the third alternative.

TRENDS IN DISPOSAL SITE DESIGN

Improvements to Existing and Planned Disposal Sites

11. Initial attention might focus on relatively simple improvements, both physical and operational, at existing disposal sites. For instance, where foundation conditions are suitable, dikes might be raised to increase storage capacity. (Note, however, that many existing dikes cannot be raised because of inadequate designs and poor construction.) Also, the District could increase the efficiency of disposal operations by using various densification techniques developed during the DMRP. These techniques (which are discussed in more detail in

Chapter 7) enhance dewatering and consolidation and thereby extend the useful life of a site and better utilize its storage capacity. Conventional sites refurbished with these types of improvements (which specifically exclude removal of DM from the disposal site) and new disposal sites using improved (rather than traditional, rule of thumb) design, selection, and operating procedures are classified "non-reusable." This classification distinguishes them from conventional sites in that proper engineering is used and full consideration is given to economic, environmental, and social impacts.

12. Unfortunately, measures which pack more dredged material into a site do not provide a long-term solution to the basic problem--the need to acquire suitable new disposal areas. Even with these measures, a non-reusable site eventually will be filled (albeit at a slower rate) and abandoned insofar as its usefulness for disposal. Obviously, these measures merely postpone the inevitable. What is needed is a fundamental change in disposal site concept, with measures such as those discussed above providing interim relief while sites based on the new concept are being designed and constructed.

Reusable Sites--The Solution

13. Reusable disposal sites provide a practical long-term solution. Moreover, they are a logical step in the evolution of disposal site design, operation, and management. By definition, a reusable site differs from a non-reusable site in that material is continuously or periodically removed from a reusable site to maintain its disposal capability.

14. The advantages of a reusable site over a non-reusable site can be categorized as follows:

• Economic--Both capital and operational savings accrue when sites convenient to dredging operations are retained and when recurring expenses of acquiring and constructing new sites are eliminated.

• Resource conservation--Useful materials for construction, land fill, soil conditioning, marsh creation, etc. might be extracted from the DM. Finding productive uses for part of the material reduces the quantity of waste for which some means of ultimate disposal must be provided.

• Environmental and social--Use of reusable sites confines any adverse environmental and social impacts to a limited number of areas. Suitable material can be used to create lush wildlife habitat (such as marshland) and to develop or enhance recreational areas (such as beaches).

15. Reusable sites can vary in complexity:

• The reusable site in its simplest form is essentially a transshipment station. It provides a centralized holding and handling facility for DM destined to be transported elsewhere with no processing. "Elsewhere" might be some final disposal area, such as an abandoned quarry; it might be some user able to accept the material in an unprocessed condition, such as for hydraulic fill; or it might be a plant processing the material into "spec products" for various users, such as highway departments.

• A more complex reusable site provides for settling and dewatering slurries. These natural processes might be accelerated by various enhancement techniques. The dewatered, unclassified material would be removed from the settling/drying basins. If kept on site, the material could be used (such as for dike construction), discarded, or stored for self-service pickup by off-site users or processors. Alternatively, it could be transported off site to a user or processor, storage area, or ultimate disposal area.

• In its most complex form, the reusable site would go beyond settling and dewatering to include facilities for processing the material to meet certain specifications. Processing might include separating coarse and fine materials, classifying, blending, etc. End products could be used or stored on or off site. Waste and excess processed material could be discarded either on site or at some off-site ultimate disposal area. This alternative would be used where the District has identified some market or need for a spec product that justifies the added capital investment and operational expenses.

16. The range of complexity of reusable sites overlaps that of non-reusable sites. Non-reusable sites also assume many forms:

- Sites of a more traditional type, which might simply be containment areas with stoplog structures to control supernatant quantity and quality to some extent.

- Improved sites, such as Craney Island in Norfolk, Virginia, with well-engineered dikes that have been raised and a size (2500 acres*) sufficient to overcome most short-circuiting problems and guarantee an effective settling pond.[4]

- Sites with a properly sized settling basin using flocculants or filters to remove fine particles, post-settling treatments to remove pollutants from the effluent, and various densification measures to increase natural drainage and evaporation and thereby enhance dewatering and consolidation.

17. A notable feature of the reusable site concept is the possibility of rejuvenating abandoned or active conventional sites. The advantages of using an existing site rather than developing a new site are many:

- Proximity to the dredging operation, hence, no need for costly improvements to the existing dredge-initial transport plant.

- Existing disposal rights (see Paragraph 20 for further discussion).

- Availability of construction materials--Coarse-grained materials suitable for dikes, etc., have fallen out of suspension near the dredge's discharge point and are conveniently separated from finer materials which are carried farther into the disposal site. The coarse material can be recovered, reducing the quantity of borrow for dike construction.

- Improved foundation conditions--Accepted methods of improving foundation conditions are often simulated by disposal operations. These include displacement of undesirable soft materials and surcharging or stage construction to increase soil strengths via consolidation.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page xix.

• Reduced environmental impact--Disposal sites have serious impacts on the local ecology due to burial of existing flora and fauna and the drastic change of environment. Clearly, it is preferable to reuse existing sites, thereby confining the impact to already affected areas, than to construct new sites and expand the area of impact. Also, the environmental impact assessment or statement for an existing site is far easier to prepare than that for a previously undisturbed site.

Of course, an existing site might not be suitable for reuse if disadvantages of location or condition offset the advantages. A problem likely to be fairly common is a lack of access to off-site users or ultimate waste disposal areas.

Reusable Sites--Possible Disadvantages

18. Reusable sites are not a panacea. Reusable sites do not completely resolve the issue of where to dispose of unusable DM. Material removed from the reusable site must be placed elsewhere. That portion useful for construction material, marsh creation, fill, etc., poses no problem as long as supply does not exceed demand. The problem is with waste, i.e., excess materials and useless by-products that must be discarded at some ultimate disposal area (which, by definition, is a non-reusable disposal site). Disposal at the reusable site might be possible for a period, but a site designed for reuse will have less waste disposal capability than the same site set up for non-reusable disposal because of area requirements for various processes, such as settling and drying basins. Therefore, in most cases, off-site transport and disposal eventually must be considered.

19. In effect, reusable sites transfer (though reducing to some extent) the problem of waste disposal. Fortunately, in most cases, new disposal options open up. Formerly inaccessible upland areas become contenders for ultimate disposal. No longer must consideration be limited for the most part to a relatively few suitable sites along the shoreline in the vicinity of the dredging operation. The advantages are twofold. First, the greater selection of suitable disposal areas

relieves the pressure from competing land users. Second, in many instances, Districts will find a less sensitive environment to contend with at upland sites than in shoreline areas.

20. Districts probably can get rights to waste disposal areas in much the same way that these rights have been acquired in the past for DM disposal sites, i.e., easements for disposal rather than outright acquisition. In the case of reusable sites, the District probably should consider acquiring title to the lands. The reasons:

- Most property owners are not interested in granting long-term use of their land, say for 10, 20, or more years. Their interest lies in reasonably short-term use leading to improvements in the land.

- Most property owners grant low- or no-cost easements on marginal lands with the expectation that these lands will be improved by placement of the DM. If the material is being removed to retain a site's disposal capability, the owner does not realize these anticipated benefits. Under these circumstances, an owner will be inclined to demand more costly lease or rental arrangements.[9]

- Ownership of the disposed material might be questioned. Generally, the material belongs to the owner of the property it is placed on unless prior arrangements for removal have been made in the disposal agreement. This subject could be very touchy, particularly in cases where the DM is being marketed. Questions of royalties to the landowner and the State might be raised.[9] Districts are urged to review Reference 9, "Legal, Policy, and Institutional Constraints Associated with Dredged Material Marketing and Land Enhancement," a report prepared under the DMRP to specifically address these types of questions.

SCOPE AND PURPOSE OF STUDY AND REPORT

21. This report is directed to Federal, State, and local government agencies and those individuals and special interest groups involved or concerned with disposal of DM. We anticipate, however, that District Offices of the Corps of Engineers will be the principal users of this document, since the Corps is responsible for most of the dredging in the United States. Therefore, in many instances, the reader will find references addressing the "District Office" as the supposed audience.

22. The scope is limited to land disposal of DM, with emphasis on the primary disposal operation. Factors that might influence the primary disposal operation include, but are not limited to: the dredge plant; DM transport, marketing, and ultimate disposal; and applicable legislation covering, for example, water quality and land-use zoning. The study incorporates findings from pertinent DMRP research projects, both completed and ongoing, as well as other, independent investigations.

23. The purpose of this report is twofold: to acquaint the reader with evolving DM disposal site concepts and to provide the reader with a procedure for selecting a disposal site type and location appropriate for his needs. The report promotes the reusable disposal site as the logical successor to the conventional disposal site and suggests that the reusable site could already be a viable alternative in many Districts. The site selection methodology relies primarily on economics to compare non-reusable containment areas with reusable disposal sites; however, likely environmental and social impacts are also given proper consideration.

REPORT ORGANIZATION

24. Chapter 2 describes in broad terms the methodology for siting and selecting the types of disposal operations needed for an efficient dredging program. Use of reusable sites is emphasized, but non-reusable sites are also discussed for cases where a reusable site is not suitable.

25. Chapters 3-10 present the methodology phases identified in Chapter 2. In each chapter, the purpose and procedure of the respective phase is explained, i.e., the reader is told why and how to proceed, and where to get the needed background information.

26. Chapters 3 and 4 discuss disposal site location criteria. Chapters 5-7 detail site design considerations and preliminary cost estimating procedures. Chapters 8-10 discuss the detailed costing and selection steps for final site selection and design. Chapter 11 briefly summarizes the conclusions and recommendations of this report. A comparison of possible secondary dredges, a list of equipment suppliers contacted, and the development and sources of equations used in the report are contained in Appendices A, B, and C, respectively.

CHAPTER 2

DESCRIPTION OF METHODOLOGY FOR SELECTION OF DISPOSAL SITE LOCATION/PROCESS

OUTLINE OF METHODOLOGY

27. The methodology provides Districts with a step-by-step procedure for identifying the most economical disposal site location and type--reusable or non-reusable--and corresponding site operation and management plan. Social and environmental constraints are factored into the selection process; impacts are weighed in choosing between alternatives that are economically similar. In this chapter, the methodology is broken down into phases, with the essential features of each phase discussed very briefly.

Phase I--Preliminary Data Collection (See Chapter 3)

- Define dredging program to be served--dredging locations, quantities, primary dredge, and dredge-to-disposal site transport system.

- Determine critical DM characteristics--physical and engineering properties, contaminants, etc.

- Locate viable markets/users and examine capabilities of regional transport system.

- Identify possible disposal sites--existing disposal sites, other undeveloped areas. Consider institutional and dredge-initial transport plant capability constraints.

Phase II--Selection of Candidate Disposal Site/Systems (See Chapter 4)

- Select viable candidate disposal sites--locations and types (non-reusable, reusable, or waste). Use clear-cut and judgmental constraints to combine individual disposal sites into alternative multisite systems capable of handling the projected DM quantity; screen out unsuitable sites. Consider dredge-initial transport plant capabilities, area/volume needs, market/user requirements, availability of off-site

transport, etc. Then use qualitative assessments of relative costs and social/environmental impacts to eliminate suitable but less desirable sites.

- Conduct necessary field studies at remaining candidate sites to collect site-specific data on: geology, groundwater, possible borrow areas, social/environmental setting, applicable effluent standards and ambient water quality, and land costs. For reusable sites, also collect information on specific market/user needs, availability of waste disposal areas, and off-site DM transport.

Phase III--Process Selection/ Preliminary Site Design (See Chapters 5-7)

- Select the specific DM processing (if any) best suited for each candidate in its role in each surviving multisite system.

- Develop preliminary layouts and cost estimates using generalized design and cost guidelines provided in the methodology. Determine total costs and impacts of alternative systems.

- Identify redundant, costly, and socially/environmentally unsatisfactory sites.

Phase IV--Candidate Screening (See Chapter 8)

- Select best disposal systems (no more than two or three). Economics is primary consideration; social/environmental impacts are used to choose between economically similar alternatives.

- Collect detailed site data--topography, foundation soils, groundwater, environment, unit costs. Conduct public information program; survey public reaction to probable impacts.

Phase V--Detailed Design and Cost Estimates (See Chapter 9)

- Adjust processes and layouts to fit additional engineering and social/environmental requirements discovered in Phase IV.

- Prepare proper engineering design and cost estimates to replace those prepared in Phase III from generalized design and cost guidelines.

Phase VI--Final Selection (See Chapter 10)

- Make final selection of disposal system site locations/processes on economic basis, with full consideration of unavoidable adverse social/environmental impacts.

28. The methodology is structured so that it may be entered or left at any stage, provided the District has the necessary inputs or outputs. For example, a District's experience might narrow the list of possible candidates to a few. This District could enter the methodology at Phase III or even Phase V if the specific disposal operation has already been selected. Conversely, a District concerned merely with the feasibility of changing its present DM disposal program might start at Phase I and exit after Phase IV when preliminary costs and operation modes of alternative sites have been determined.

DISTRICT INPUT

29. The District plays a vital role in the methodology beyond that of just providing obvious inputs, such as field data on candidate sites, dredge plant, DM, etc. The methodology relies on District experience and judgment at several key decision-making points. This is particularly evident early in the methodology during initial selection of the number, location, and operational mode (non-reusable or reusable) of the candidates. Without this early decision-making, the methodology would become impossibly cumbersome; detailed analyses would have to be made for all possible alternative disposal operations at all likely sites, an impracticably costly and time-consuming task.

30. In Phase I, for example, the District must identify possible disposal sites and, for reusable disposal sites, likely markets/users and potential waste disposal sites. In some cases, the decision will be straightforward. A candidate area with poor landward access likely will not be suitable for a reusable site requiring off-site transport of products and wastes. However, this same candidate might serve satisfactorily for a non-reusable site where the material need not be removed. The methodology provides guidelines to assist in these decisions,

but experience and judgment still play a major role. Obviously, a more efficient study can be conducted if the study area is well-known. District personnel can focus on a small number of better candidates rather than cover a large number of candidates with varying potential.

31. In Phase III, the District selects specific operations for each candidate site. These decisions are made on the basis of a market analysis and a review of planned land-use developments, anticipated legislative trends (particularly in the environmental field), projected dredging quantities, etc. However, these decisions still amount to subjective assessments because the above factors can change quickly.

32. The most important subjective judgments are made in Phases I-III. Later in the methodology, decisions become more objective as the number of alternatives decreases. The fewer alternatives permit more extensive analysis, hence more quantitative measures of economic, social, and environmental factors. Clearly, however, the District's decision-making power is never usurped by the methodology; the methodology merely provides the District with a tool laying out all the pertinent factors in a logical, step-by-step manner.

33. The District should approach the methodology with the attitude that the results of this study, if adopted, will be <u>the</u> major influence on the dredging program over the next 10, 20, or more years. Accordingly, the District should be prepared to make a serious commitment in terms of manpower, time, and money.* Savings will result if records of the District's dredging program are complete, accurate, and up-to-date and if District personnel are very familiar with the study area. Conversely, should much original data generation be necessary

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* A purely conceptual study or a study involving only one or two dredging locations will be smaller in scope, thereby reducing the magnitude of the study considerably.

or should weather conditions interfere with field studies, expenditures of time and money will be greater than normally might be expected.

REFERENCE MATERIALS

34. The reader will notice references in the text identifying pertinent reports from the DMRP and independent studies. It was deemed impractical to incorporate within the methodology all the key information from these many references. In some cases, large portions of a report would have had to be included, e.g., to adequately describe new DM densification techniques or to cover fully the criteria for marsh creation candidates and the proper material placement procedures for marsh creation. Also, because of the quantity of useful material, appendices were considered impractical for all but the most vital information. Comprehensive appendices would have required multiple volumes, offering no significant advantage over having the referenced material itself on file.

35. The text identifies available reports needed to conduct the methodology. The District should acquire those reports it deems vital to its particular investigation. Referenced studies not completed when this report was written should be reviewed as they are published. Certain items in the methodology might be modified in light of these later reports.

CHAPTER 3
PHASE I
PRELIMINARY DATA COLLECTION

OVERVIEW

36. The first phase of the methodology sets the scene for the remaining phases. Basic data are gathered; fundamental decisions, many of them subjective, are made regarding markets/uses, dredge and transport plant, possible disposal sites, etc.* The essential steps in this phase include:

- Analyze dredging locations and quantities; project to future.
- Determine DM characteristics and possible products.
- Identify possible market/user locations and potential.
- Identify social, environmental, and institutional factors.
- Study regional transportation network.
- Analyze potential of existing disposal sites.
- Locate other lands suitable as disposal sites.
- Select dredge-initial transport plant.

DREDGING LOCATIONS AND QUANTITIES

37. Dredging locations and quantities are two of the most important considerations in selecting disposal sites. Long-distance transport

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* The District might acquire a useful insight into current inland disposal practices and concepts by reviewing the results of DMRP Work Unit 3B02, "Literature Review on Feasibility of Inland Disposal of Dredged Material."

of DM from the dredging operation is an expensive proposition. Water makes up a significant portion of the slurry as it comes from the dredging operation--about 90 percent by weight from a hydraulic dredge, less from mechanical and hopper dredges which allow some excess water to escape. Hauling large volumes of water incidental to the DM solids can be expensive and highly undesirable (unless, of course, transport is by pipeline). Generally, the closer the disposal site is to the dredging operation, the better. However, the economic advantages of close-in sites must be weighed against the extra costs of having multiple disposal sites to serve widely spaced dredging locations. This consideration will become even more important as disposal sites and operations become more complex and costly, which will be the situation with properly engineered dikes and effluent control systems. Selection of the dredge-initial transport plant, which is discussed later, will involve consideration of these factors.

38. District records of dredging locations and quantities should be reviewed and collated. Attention should focus on locations that will be a source of DM during the time period selected for the study. Maintenance dredging will probably be the major contributor. Foreseeable one-time dredging operations that will require disposal also may be included, e.g., clearing sediment for bridge pier construction. Dredging operations not involving DM disposal should not be included, e.g., providing hydraulic fill.

39. The St. Paul District developed a means of presenting dredging locations and quantities in a compact, comprehensive manner.[10] Figures 1 and 2 provide an example. Figure 1 shows dredging and disposal locations along a specific reach of the Mississippi River. This figure could become an even more useful tool by displaying possible markets/users, other undeveloped lands suitable for DM or waste disposal, and major transport routes, both land and waterborne.

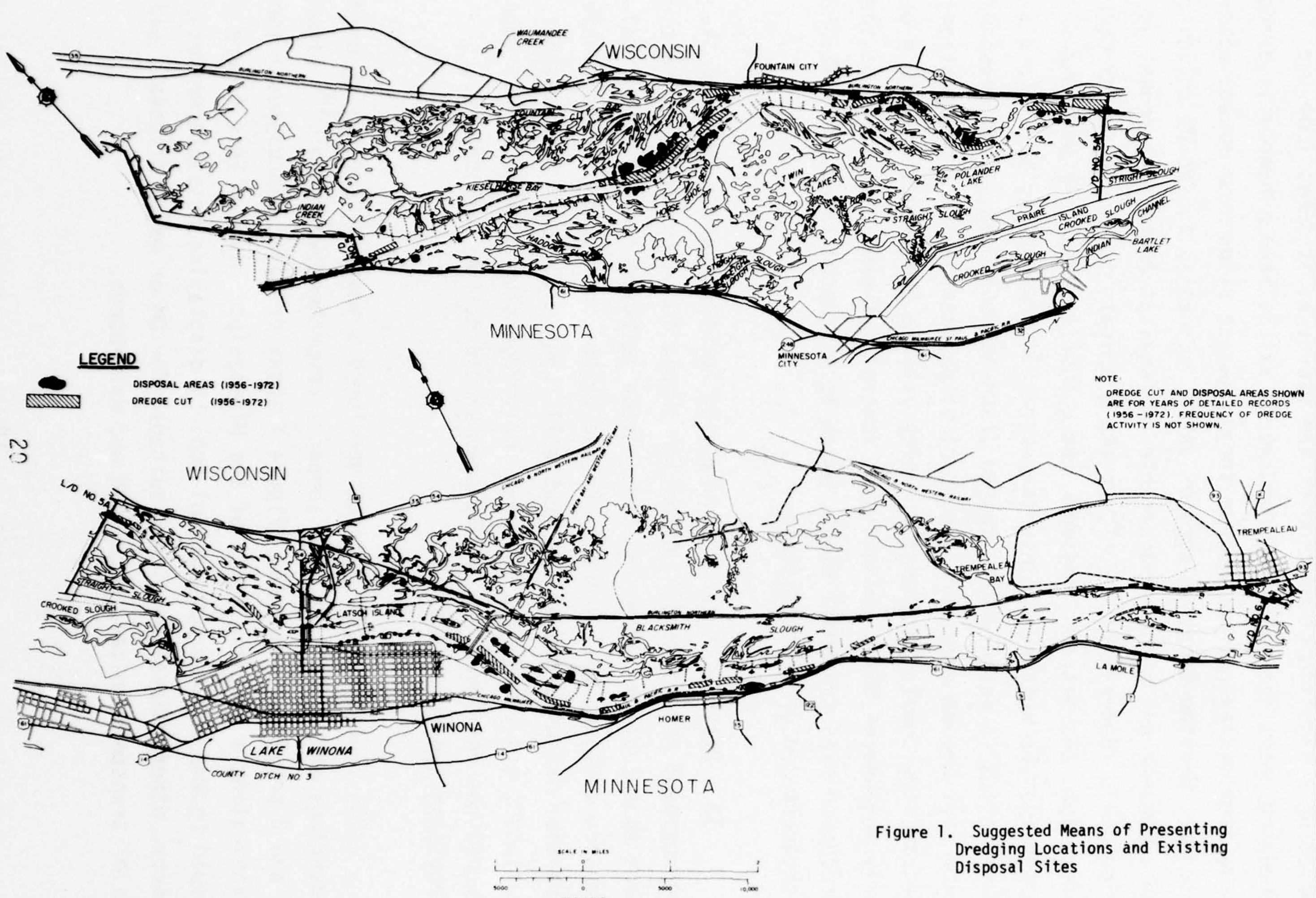
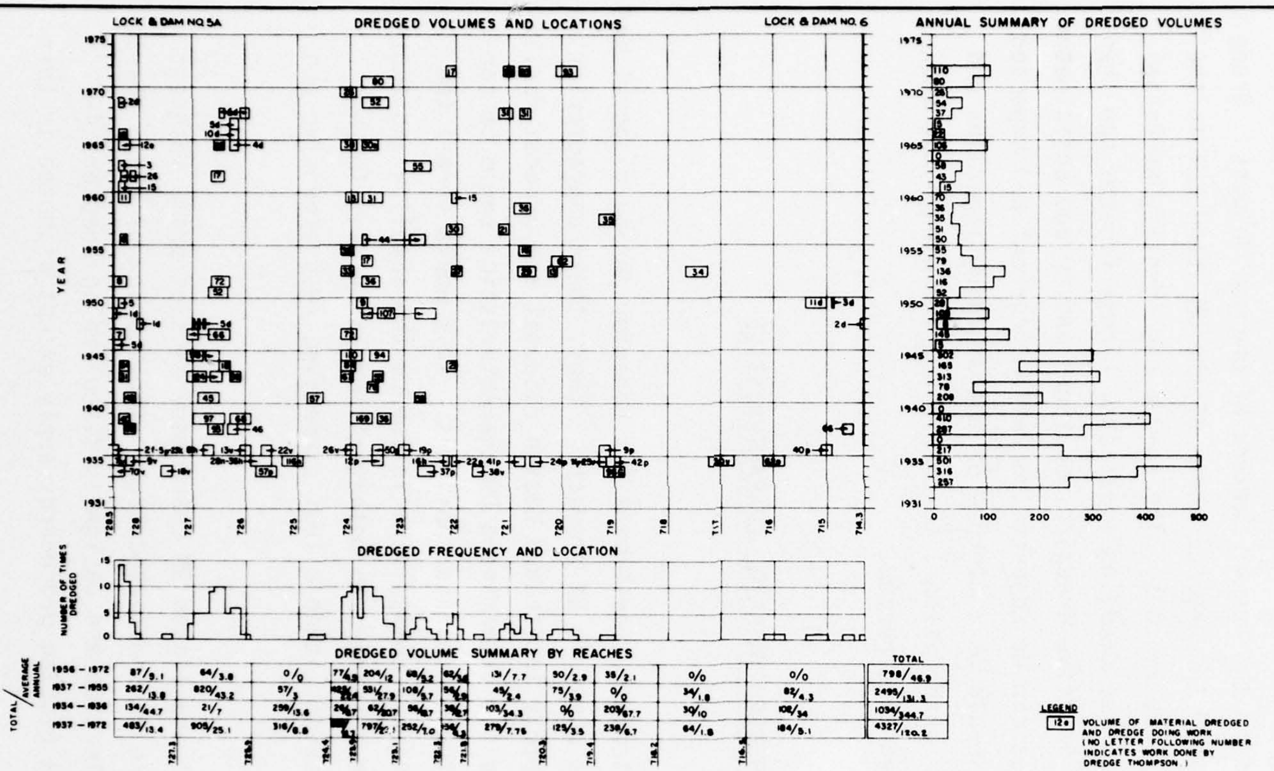


Figure 1. Suggested Means of Presenting Dredging Locations and Existing Disposal Sites



DREDGE CODES

CODE	DREDGE	
d	DERRICKBARGE HAUSER	CLAM SHELL
b	AMY A (CONTRACT)	HYDRAULIC
c	CRANE BARGE 771	CLAM SHELL
e	BEAVER (CONTRACT)	HYDRAULIC
f	DERRICKBOAT 556	CLAM SHELL
g	GEYSER	HYDRAULIC
h	CANADA	HYDRAULIC
j	DERRICKBOAT 566	CLAM SHELL
k	LA CROSSE 84 (CONTRACT)	HYDRAULIC DUST PAN
l	SEIMS HELMER DRAGLINE (CONTRACT)	DRAGLINE

CODE	DREDGE	
m	LA CROSSE	HYDRAULIC
n	DUNDEE	HYDRAULIC
p	PELEE	HYDRAULIC
r	ROCK ISLAND	HYDRAULIC
s	DIPPER DREDGE ST PAUL (CONTRACT)	DIPPER
t	TAAL	HYDRAULIC DUST PAN
v	VESUVIUS	HYDRAULIC
x	A KERTZMAN (CONTRACTOR)	HYDRAULIC

Figure 2. Suggested Means of Presenting Dredging Locations and Quantities

40. Figure 2 provides a tabular summary of historic dredging data for the same reach of river. Dredging activity is illustrated both by year and by river mile. Trends in dredging quantities over the years are made very evident in the Annual Summary of Dredged Volumes. Dredging locations that yield the greater share of the DM stand out in the Dredged Volume Summary by Reaches. The reader can identify perennial, intermittent, and inactive dredging locations. These figures can then be revised to delete inactive dredging locations and to add anticipated locations. Quantities can be adjusted to reflect current and expected trends. The result should be a picture of the dredging locations and quantities (annual or intermittent) to be planned for within the study area over the selected time period.

DREDGED MATERIAL CHARACTERISTICS

General

41. DM characteristics determine its behavior during disposal and processing and define possible DM products. Thus, these characteristics must be known to properly locate and design disposal and process facilities. The time frame for determining DM characteristics could be continued past that of the market/user analysis. This would permit the results of the market/user analysis to influence the sampling and testing program. If, for instance, no potential market or user for any possible DM product exists, then a less extensive, less expensive program might suffice.

42. In Table 1 are listed DM characteristics of prime interest and their significance in the methodology. Application of these characteristics in site selection and design is discussed in Chapters 4-7. Standard sampling and testing procedures apply except as noted in this chapter.

Table 1

Dredged Material Characteristics
Of Prime Concern

Characteristic	Need In Methodology
Gradation Curve	Particle sizes and size distribution establish settling characteristics, hence containment area dimensions. Size distribution also fixes possible end products, therefore processing equipment selection.
Bulking Factor	Predict disposal site storage requirements by applying the bulking factor to forecasted quantities of in situ DM.
Solids Specific Gravity	Affects settling and scour velocity of particles, hence settling basin surface area and minimum water depth, respectively.
In Situ Bulk Density	Provides tonnage from known volumetric dredging rate; used in conjunction with gradation curve to estimate quantities of various products.
Chemical/Organic Characteristics	Identify organic content and possible contaminants, need for treatments, special design provisions, limits on DM end use. The appropriateness of recognized chemical/biological tests to disposal site selection and design is discussed later in this chapter.

43. Other engineering and physical properties of the DM--plasticity, shear strength, compressibility, and permeability--are not inputs to the methodology since they do not serve as a basis for process selection. However, as properties of end products, they are of great interest because they determine the suitability of the processed material for a proposed end use. Unfortunately, end product properties generally cannot be accurately predicted. In most cases, when controllable characteristics, such as moisture content and gradation, are brought to spec during DM processing, these other properties can be expected to fall into an acceptable range. This is not always true, however, since these properties are also influenced by uncontrolled factors, such as particle shape/angularity. Other DMRP studies (identified in Paragraph 75) are addressing the productive use of DM. Reports from these studies should provide the reader with the means to assess the suitability of a given DM for a proposed end use.

Sampling

44. The sampling program must be planned carefully to ensure that the samples are representative. A bad technique, for example, would be to assume that samples from existing on-land disposal sites are representative of a District's DM. Material from an unconfined site is much coarser than in situ DM because fine-grained material is carried off by the dredge's discharge and by subsequent precipitation on the exposed material. Material will vary in grading with distance from the dredge outfall. At a confined site, many fines will have been lost in the effluent, particularly if the site is poorly designed or operated.

45. Both in situ and "as delivered" samples will be needed, depending on the particular characteristic. For in situ samples, a standard grab or core sampler is satisfactory, but care should be exercised to ensure that the samples are representative. The considerations involved in selecting sample locations are discussed in Paragraphs 47 and 48.

46. "As delivered" samples represent the condition of the material as it would arrive at the disposal site. This procedure is recommended for determining the gradation curve, solids specific gravity, and chemical/organic content. It is particularly important with the gradation curve since settling basin size and various solids removal and processing systems are <u>very</u> sensitive to changes in gradation.* Taking "as delivered" samples overcomes two potential sources of gradation curve error:

- The particular dredge-transport plant being used can drastically change the gradation curve from its in situ state. A hopper dredge, for example, often continues pumping into its hoppers until the quantity of solids is near maximum. The overflow from the hoppers carries with it a large amount of fine-grained particles. Thus, the material delivered to the disposal site is coarser than in situ DM. (With a cutterhead pipeline dredge, there would be less of a discrepancy between in situ and "as delivered" gradation.)

- An "as delivered" sample accurately reflects the degree of dispersion caused by turbulence during dredging and transport. The usual laboratory practice of applying a dispersing agent to an in situ sample breaks up naturally agglomerated materials (i.e., fine particles which have aggregated to form larger particles) far more effectively than in an "as delivered" state; this tends to overemphasize the fine fraction. Field studies have shown settling basins to be more effective than predicted.[11] This can be attributed to predicting on the basis of a dispersed sample rather than a sample representative of the "as delivered" condition. The suspended material reaching the monitored disposal sites still included agglomerated materials which settled faster than laboratory tests indicate; dispersion in the field was not as thorough as that in laboratory tests.

47. Dredging locations selected for in situ and "as delivered" samples must be representative. Gradation curves, for example, will vary from dredging location to dredging location and even within a single dredging location because of local differences in sedimentation

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* If two or more dredges must feed the same disposal site, the site must be designed to handle the "worst case" situation.

processes. Consider two typical dredging locations that might be served by a single disposal site: a sediment-laden tributary entering a river is introducing material too coarse-grained for the river to transport; a wide section of this same river causes reduced velocities and deposition of even fine-grained sediments. A settling basin properly sized to retain the fine-grained material from the wide reach of the river would be overdesigned for the coarser material deposited by the tributary (i.e., the basin would retain more material than necessary). Conversely, a basin sized to handle the coarse-grained DM would be underdesigned for the finer material, and effluent quality would suffer. Separate disposal sites is a possible solution (albeit expensive in its redundancy); but the point is that planners and engineers must know the DM characteristics to make informed decisions regarding the number of disposal sites, their locations, and designs.

48. Sediment characteristics also vary with time. Within any given year, floods from spring snowmelt or isolated precipitation events can drastically alter the sediment picture. Normal or low flows might be capable of moving only fine-grained particles; but the high discharges during floods can scour a river bed and transport even coarse-grained material long distances. Chemical/organic characteristics also will vary, but on a more predictable seasonal basis. Fertilizers, herbicides, and pesticides, for example, will be introduced into the sediments via runoff from agricultural areas. Optimally, samples should be taken near the time of year when dredging of the site generally takes place. Even this method, however, cannot prevent descrepancies from random runoff events or year-to-year variations in precipitation or runoff.

49. The unavoidable variability of DM characteristics from location to location and from time to time results in a range of values for each parameter of interest. Consider the consequences of a gradation "band" rather than a single gradation curve. The District has a difficult decision regarding what to use for disposal site design. Designing a settling basin in accordance with the "average" gradation

curve--even a weighted average curve--guarantees that part of the time the effluent will not meet design standards. If this occurs only a small part of the time, perhaps this will be acceptable. But what is the cutoff--10 or 20 percent of the time?*

50. We recommend that the fine-grained limit of the gradation band be the basis for design. However, even this more stringent criterion cannot guarantee effluent compliance 100 percent of the time because the samples used to prepare the gradation band likely do not encompass extreme cases that might be encountered. Fortunately, some disposal systems developed in this study can handle reasonable variations in gradation by adding more flocculating agent in the final solids removal phase.**

Bulking Factor

51. The bulking factor is defined as the ratio of the volume occupied by a given weight of material after disturbance and settling to the in situ volume of the material. Bulking factors can vary considerably depending on gradation, organic content, and sedimentation processes at the dredging and disposal sites.[12] Therefore, we recommend that the bulking factor be determined on a case-by-case basis rather than relying on generalized values for various categories of materials.

52. The method used to determine the bulking factor depends on the type of disposal operation. For a non-reusable disposal site which relies on unassisted settling and consolidation, the bulking factor can

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* Obviously, the District should carefully review applicable regulations and standards in making this type of judgment.

** Disposal systems with this capability are shown in Table 7, Chapter 5, specifically, Cases 3 and 6-3, which are systems incorporating a Final Solids Removal (FSR) facility. Gradations finer than the design curve result in higher influent concentrations to the FSR facility and require more or a different flocculating agent. The FSR facility is discussed in detail in Chapter 7.

best be estimated by examining existing disposal sites handling the same DM and comparing the volume of material stored to that dredged according to records.* Alternatively, a bulking factor based on laboratory tests of the in situ material to be dredged can be used to estimate storage requirements.

53. Actual bulking in a settling basin could be significantly higher or lower than that predicted from an in situ sample. Part of the problem is the coarser gradation curve at the disposal site because of fine material losses during dredging and via the disposal site effluent. Also, bulking could vary within a single settling basin because of the gradation spectrum caused by coarse-grained particles settling nearer the influent than fine-grained particles. The "composite" bulking factor of the in situ sample will not necessarily equal the "average" bulking actually found in the settling basin.

54. If densification techniques are used to enhance consolidation in a non-reusable disposal site, the "bulking factor" of the densified DM may be significantly less than the bulking factor value for unassisted settling and consolidation. However, a reliable way to accurately predict the eventual degree of consolidation of DM (short of prototype tests) has not yet been developed. The District could conservatively size basins on the basis of the bulking factor for unassisted settling and consolidation, but the overdesign might be unnecessarily wasteful in terms of cost and space.

55. A different bulking factor must be used to design an ultimate (waste) disposal facility. Usually, waste slurry will be the by-product of a coarse material recovery process. Accordingly, an estimate of the bulking factor can be made using an in situ sample which has had the

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* Using this procedure, one must be cautious of the effect on the bulking factor due to possible material losses during dredging and from poorly designed and operated containment areas.

coarser grained particles removed (via screening or settling) to simulate the gradation curve of the waste solids. Again, a caution is in order because the fines content of the actual waste will probably be less than that of an in situ sample with coarser material removed due to losses during the primary dredging-transport operation and via the disposal site effluent.

In Situ Bulk Density

56. The bulk density (dry weight) of the material to be dredged can provide a quick estimate of the production rate of certain end products. The bulk density is multiplied by the volumetric dredging rate (in cubic yards per year) and that fraction of the gradation curve corresponding to the particular end product under consideration. Practice has shown that an adjustment factor may also be necessary.* This procedure is valid for the coarser end of the gradation curve, but must be used with caution for fine-grained materials because an unknown but appreciable portion of the fines may be lost with certain dredging equipment.

Chemical/Biological Testing

57. During the initial search for candidate disposal sites, chemical/biological tests are useful only if they assist the District in predicting candidate site suitability. The District's decision will be influenced by the following items:

- Effluent quality--Could a disposal/processing facility readily meet local water quality standards? Is there room for an adequate mixing zone? If not, what effluent treatments would be needed?

- Leachate quality--Will leachates contaminate groundwater? Is an impermeable liner or subsurface leachate collection/treatment system needed?

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* Chapter 5 presents examples wherein the production rates of ASTM (American Society for Testing and Materials) Fine Aggregates and non-spec products are estimated from a given DM gradation curve and DM delivery rate.

• Solids quality--Is any process or end use precluded? If so, what treatments would solve the problem?

If the chemical/biological tests answer these questions, then the District can decide if the economic costs for solving the problems revealed preclude use of the candidate site for reusable, non-reusable, and/or waste disposal. Below, we discuss predicting the performance of a proposed confined disposal site using two chemical tests (elutriate and bulk sediment) and one biological test (bioassay).

58. Elutriate Test--Most contaminants released during a dredging or disposal operation (with the exception of ammonia and manganese) are quickly sorbed by suspended particulates under oxygenated conditions,[13, 14, 15] i.e., most contaminants are removed from the water column as the solids settle out. Hence, containment area effluent quality largely depends on the suspended solids load and dissolved oxygen concentration at the site's outfall. Unfortunately, the elutriate test procedure models short-term releases of dissolved substances such as occur during dredging and open-water disposal operations; the test does not simulate the long retention (settling) periods characteristic of containment operations and probably cannot be used to predict containment area effluent quality. However, it can be concluded that effluent from a properly designed confined disposal site should be of higher quality than an elutriate test indicates.

59. The inapplicability of elutriate test results in cases of confined disposal also affects mixing zone procedures. Mixing zone determination requires foreknowledge of contaminant concentrations.[16] For open-water disposal, the elutriate test has been designated as the means to determine these concentrations. However, as discussed above, the elutriate test cannot accurately predict water quality at a containment area. Therefore, it appears that a mixing zone for effluent

from a confined disposal site cannot be predetermined.* Only after a site is constructed and in operation could reliable measurements of effluent quality be made and used to determine the mixing zone and a possible need for add-on treatments.

60. Leachate passing through the dikes above the sediment-water interface of a confined disposal basin will generally be of even higher quality than that of the effluent from the basin (because of the filtering action of the surrounding dikes). Thus, the elutriate test is, if anything, even less accurate in predicting the quality of this leachate than in predicting effluent quality.

61. The quality of leachate passing through the sediment is affected by retention time, because anoxic conditions could develop in undisturbed sediment. Also, the high solids-to-water ratios in the sediment encourage release of contaminants to the interstitial water. Under these conditions, significant amounts of nutrients (Kjeldahl nitrogen, phosphates), ammonia, manganese, iron, and lead may be released from sediments.[13] A modified elutriate test could simulate "worst case" releases into the interstitial waters under anoxic conditions. Test modifications would include the use of increased sediment-to-water ratios and the substitution of compressed nitrogen for compressed air for agitation. The results of such a modified elutriate test would be a basis for comparing the suitability of alternative disposal sites, forecasting the need for a leachate control system, or increasing the frequency of sediment removal in a reusable site to

* Elutriate test results could be interpreted as "worst case" conditions which, in turn, could be used to compute the probable maximum mixing zone size.

prevent oxygen depletion. However, at present no such standardized test has been developed for District use.*

62. Bulk Sediment Analysis--DMRP studies have repeatedly demonstrated the inadequacy of bulk sediment analysis as an indicator of water quality.[13,15] Because of the many chemical interactions, there is no simple relationship between the quantity of contaminants sorbed to sediments and the concentrations of dissolved substances in waters contacting these sediments. Hence, bulk sediment analyses are not recommended as a means of predicting effluent or leachate quality. However, such tests may be appropriate as indicators of sediment quality. Thus, bulk sediment analyses might detect contaminants (such as oils, greases, and organics) that would affect the engineering properties (hence, possible uses) of dredged material or that would preclude certain types of disposal site processing or equipment. Under the worst case assumption that there are no significant losses to the effluent or leachate, sediment contaminant levels of the final "product," be it for use or disposal, would equal those of the incoming slurry. Where sediments are graded into coarse- and fine-grained materials on site, the worst case assumption applies particularly to the fines where contaminants tend to concentrate; coarse material is relatively clean.

63. Bioassays--The use of bioassays during preliminary candidate selection would be costly, time-consuming, and premature. Bioassays involve the monitoring of sensitive organisms exposed to various concentrations of test solutions to determine their impacts. If test solutions representative of disposal site effluents could be prepared, bioassays could be conducted. However, as previously discussed, there

* The District should refer to DMRP Work Units 2D01, "Physical and Chemical Characterization of Contaminated Dredged Material Influents, Effluents, and Sediments in Confined Upland Disposal Sites," and 2D02, "A Study of Leachate from Dredged Material in Upland Disposal Sites and/or in Productive Uses."

is presently no reliable way to predict the chemical quality of effluent from a confined disposal site.

64. Bioassays would be most useful during the early stages of site operation, when effluents could be monitored to determine impacts on organisms of local importance.* If serious concerns arise, corrective action could be taken, e.g., process modification, effluent polishing, or outfall relocation.

65. We recommend that in the absence of useful chemical/biological test results, the settling basin be designed and constructed to meet appropriate suspended solids standards.** As discussed earlier, most contaminants will be removed from the water column with the settling solids, but the degree of removal cannot be accurately predicted. However, containment area effluent should be of better quality than elutriate test results indicate. Thus, if an elutriate test shows certain contaminants are released in concentrations near to or less than allowable water quality standards, these contaminants should present no problem in a containment area's effluent. On the other hand, no firm conclusions can be made regarding contaminants whose concentrations substantially exceed allowable limits; these contaminants might or might not be excessive in the effluent.***

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* Seasonality of organism activities might require monitoring for up to a year to cover all possible impacts. If some sources of contaminated DM are dredged at periods exceeding one year, monitoring of the disposal site in question would have to be reinstituted at these times to determine changes in effluent quality.

** Chapters 5-7 present design procedures.

*** As discussed in Paragraph 46, much fine-grained material, which is particularly rich in contaminants, can be lost during dredging and transport to the disposal site. Therefore, we recommend taking samples of the DM as it would arrive at the disposal site. This differs from the standard practice of taking in situ sediment samples at the dredging location.[16] This recommended sampling procedure should give test results that provide a more accurate appraisal of contaminant concentrations at the disposal site.

66. Based on the elutriate test results, site design and construction can incorporate built-in provisions for adding treatments to eliminate the possible pollutants that have been identified. The actual need for these treatments will be determined by monitoring the site's effluent during operation, in which case there may be a period when site effluent would not meet all water quality standards.

POTENTIAL MARKETS/USERS

Introduction

67. If reusable sites are being considered, the District should conduct a survey to identify potential markets/users.* The basic precept of a reusable site is removal of material to restore the site's storage capacity. Obviously, this material must be placed elsewhere. If a portion can be used productively, this reduces the scope and hence the costs of waste disposal. Also, the DM (perhaps with some processing) can conserve existing supplies of certain raw materials by serving as a supplemental or replacement source. In some instances, DM products can provide a financial return to the District to partially offset the costs of the disposal operation.

68. A word of caution is in order here. Because of legal complexities regarding DM ownership, State royalties, etc., we urge Districts to read Reference 9 (a DMRP study of legal constraints on DM marketing and donation) and have their Counsel investigate the latest Federal, State, and local laws that might pertain. Reference 9 concluded that "material disposed of to other than governmental tax-supported or nonprofit organizations, e.g., a commercial enterprise, must be sold at its fair market value."[9] This could put the District in an awkward position, particularly if the supply of similar materials is tight:

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* For the purposes of this report, a "user" is defined as any individual, business, government agency, etc., willing to utilize DM. A "market" is simply a user or users willing to pay for the DM.

• If the District attempts to deal directly with "consumers" (such as persons needing landfill), this places the District in direct competition with commercial suppliers of raw materials. If the District allows its price to float (via competitive bids) in order to unload a large quantity of DM-derived material at a "fair market price," this will tend to take business away from commercial suppliers of similar materials and perhaps force them to cut prices to recover sales volume. Clearly, there would be strong opposition from commercial suppliers to such a District policy. Alternatively, the District could set prices that do not undercut those charged by commercial suppliers. Realistically, however, DM-derived material is viewed with suspicion by many people, effectually making its "market value" less than that of similar material derived from a normal source of supply. Therefore, this policy might severely curtail sales of DM-derived materials. And even limited sales will still be opposed by commercial suppliers who might otherwise have made the sale. (Note, however, that Reference 9 cites many instances of sales and donations apparently without serious opposition from commercial suppliers.)

• The District could avoid the competition issue by dealing with commercial suppliers via competitive bidding, with the commercial suppliers then retailing the DM products to consumers. It is possible, however, that the bids received will not entirely cover the District's costs for processing and transporting the material. This would give an appearance of subsidization, which conflicts with past Corps policy wherein added costs for disposing DM for the benefit of some individual must be covered by the beneficiary. This official policy, however, has been abrogated in recent years. Many Districts are incurring added costs to prevent alleged environmental degradation with the "beneficiary" being the American people.* In a specific case, the St. Paul District is absorbing additional transport costs to remove DM from the environmentally-sensitive floodplain and make it available for productive uses. Beneficiaries include local governments, e.g., the City of Minneapolis, Minnesota, and a commercial firm.[17] The DMRP legal constraints report suggests that the subsidy issue might be avoided if the Corps would "place the material on state-owned or controlled sites...and encourage the states to let competitive or negotiated contracts to reclaim the material, <u>even if they [the states] have to subsidize the contractor</u>"[9] (emphasis added).

69. The ultimate fate of DM at a non-renewable disposal site need not concern the District. If a Federally-owned non-reusable site is to be used as a source of DM products, this site reverts to the definition

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* It could be argued, however, that commercial recreational interests and a relatively narrow segment of the population are the prime beneficiaries.

of a reusable site. If DM from a privately-owned non-reusable disposal site finds its way to the marketplace, that is at the option of the landowner and does not involve the District (which usually has acquired disposal rights only).

Market/User Survey

70. If the District intends to deal solely with commercial suppliers of raw and fill materials, the survey scope is narrowed considerably. The relatively few suppliers will be specific in defining their needs in terms of product specs, quantities, and possible revenues. If the District elects or is forced by lack of interest on the part of these suppliers to deal directly with consumers, the survey is greatly expanded. In either case, the survey must develop the following information:

- Identify potential customers for DM products (both raw material suppliers and/or actual consumers). Adverse locations of customers (because of distance or relative inaccessibility from possible disposal areas) could preclude productive use of the DM and, therefore, affect the types of processing at the reusable site. Customer location can also influence reusable site location. For example, it would be advantageous from a transportation standpoint to locate a reusable site on the same side of a river as a potential major customer.

- Quantify the potential demand. If the survey shows a substantial demand for products requiring extra processing (e.g., ASTM Fine Aggregates) but little demand for unclassified material, then the District must weigh the advantages of reducing the waste disposal problem by the amount of DM that could be consumed versus the added costs for the equipment and multistage handling needed for the processing. To assist in this decision, the survey should assess revenue possibilities.

- Determine possible revenues. If revenues from the sale of a specific product can offset the added costs for the extra processing, site design should include the necessary equipment. Even if the added cost is not entirely offset, sufficient savings might accrue from reduced waste disposal costs to justify the extra processing.

71. If the District has had the foresight to determine its DM characteristics beforehand, then likely products and production rates can be used in the market/user survey. The advantages are obvious:

- Survey costs will be reduced since the District can immediately focus on customers of specific products rather than covering the entire spectrum of customers for all possible DM products.

- Survey results will be more accurate since interviews with potential customers can be specific rather than tentative in terms of products and quantities. Revenue estimates by the customers will be more serious and precise.

72. Alternatively, if the District must conduct the survey without the benefit of knowing specific products and production rates, the survey becomes more of a poll to determine local raw material needs and possible unit revenues given various supply rates. Later, when the DM characteristics are available, the District can assess its ability to meet the demands revealed by the survey and the possible revenues therefrom.

73. Although the survey eventually boils down to a canvass of possible DM customers, the first target of the surveyors should be groups and government agencies with a planning function, e.g., regional planning commissions, economic development councils, various agencies (highway departments, port authorities), etc. These agencies establish development trends (hence, future raw material needs) via recommendations on land-use policies, controls on sewer and water services, building codes, etc. Reference 18 provides an overview of future landfill and construction material needs on a regional basis for the coastal States. This same type of assessment, but on a local, more detailed basis is what is needed.

74. Because of the large quantities of DM, survey efforts should concentrate on potential major customers, such as those listed in Table 2. However, the District should not neglect small customers.

Table 2

Potential Major Customers For Dredged Material Products

Customer	Typical Needs
Raw material suppliers (sand and gravel mining and processing operations)	Material needs dictated by consumer being served. Requirements might be as simple as clean, organically-free material; or as stringent as separated coarses with a particular grain-size cutoff.
Developers, construction firms	Landfill (classified and unclassified), subsidence fill, road embankments, earthfill dams, levees, shoreline restoration, aesthetic treatments (mounding, soil conditioner).
Mining industry	Fill and nutrient-rich cover for strip mines, quarries, underground mines.
Highway departments	Material for road base; fill for embankments; sand to spread on icy roads.
Asphalt and concrete plants	Sand for portland cement and asphaltic concrete mixes.
Solid waste agencies and private firms	Cover for sanitary landfill operations.
Environmental organizations and agencies (Corps, State environmental and natural resources bodies)	Material for wildlife habitat creation (wetlands, bird island).
Recreation agencies (local parks and recreation departments, Corps)	Fill for parkland development; beach nourishment.
Agricultural interests	Soil conditioner, nutrient-rich cover; fill for erosion-prone fields and streambanks.

The cumulative effect from individual homeowners, neighborhood nurseries, etc., hauling off stockpiled excess material for fill or soil conditioner might be significant.

75. Because of DM's poor reputation, the District must actively promote DM use. DMRP studies are excellent references to cite when discussing DM's suitability for various productive uses. Table 3 lists completed and ongoing DMRP studies that might be of particular value in assisting the District in identifying and promoting DM use and identifying any special requirements, e.g., processing, handling, and site preparation.

SOCIAL, ENVIRONMENTAL, AND INSTITUTIONAL FACTORS

76. Social, environmental, and institutional factors include:

- Absolute constraints which unqualifiedly preclude the presence of a disposal site. Special dispensation would be required to locate a disposal site despite an absolute constraint.

- Judgment considerations involving quantifiable ("so many acres") and unquantifiable ("aesthetic degradation") factors. Judgment items can be used to eliminate poor sites that are not eliminated by absolute constraints and to roughly rank remaining sites as to their relative beneficial and adverse impacts.

The District should consult Reference 5 which addresses specific concerns in these areas.

77. Absolute constraints include environmental and institutional factors such as:

- Wildlife preserves.

- Habitat of rare and endangered species--Consult local museums and universities for lists of such species and for local sightings.

Table 3

DMRP Studies and Reports of Productive Uses for Dredged Material

Type of Use	DMRP Study Title (Work Unit)	WES Report
General	Classification and Determination of Engineering and Other Physical Characteristics of Dredged Material (5C02)	NA*,**
	Case Studies and Comparative Analyses of Issues Associated with Productive Land Use at Dredged Material Disposal Sites (5D02)	NA
	Review of International Literature on Productive Land Use of Dredged Material Containment Areas (5D03)	NA
	Land Application of Waste Materials from Dredging, Construction, and Demolition Processes	Miscellaneous Paper D-76-5[19]
Strip Mine Rehabilitation	Use of Dredged Material to Reclaim Strip-Mined Land: A Preliminary Investigation (4C01)	NA
Solid Waste Disposal	A Feasibility Study of Dredged Material Use in Conjunction with Solid Waste Management (4C02)	NA†
Wildlife Habitat Creation	Study of Identification of Relevant Criteria and Survey of Potential Application Sites, Including Test Sites, for Artificial Creation of Marshes (4A01)	Contract Report D-76-2[20]
	Development of Guidelines for Material Placement in Marsh Creation (4A08)	Contract Report D-75-2[21]

(continued)

* NA--Not available in published form at the time this report was written.

** Now (May 1978) available as Technical Report D-77-18.

† Now (May 1978) available as Technical Report D-77-11.

Table 3 (concluded)

Type of Use	DMRP Study Title (Work Unit)	WES Report
	Survey of Critical Nesting and Migration Areas of the Great Lakes and Comparisons of Dredged Material and Natural Island Breeding Habitats (4F01A)	NA
	Review and Examination of Disposal Area Filling Techniques and Rates to Identify Nonconflicting Wildlife Enhancement Alternatives (5B04)	NA
Recreation Area Creation	Socio-Economic Aspects of Dredged Material Disposal: Creation of Waterfront Recreational Opportunities in Urbanized Areas (5D01)	Contract Report D-76-6[22]
Soil Conditioner/ Nutrient	Potential of Dredged Material as an Agricultural Soil and/or Amendment (4C03)	NA
	A Feasibility Study of Lawn Sod Production and/or Related Activities in Dredged Material Disposal Sites (4D01)	Contract Report D-75-1[23]

• Incompatible existing and planned developments/zoning--Confer with local (muncipal and county) authorities and planning agencies.

• Floodplain ordinances--Consult the local HUD office and local government agencies.

• Archeological and historical sites--Confer with local museums and universities; reference the National Register of Historic Places.

• Indian reservations--Confer with local offices of the Federal Bureau of Indian Affairs (Department of the Interior), State agencies, and tribal leaders.

• National, State, and local parks, recreation areas, monuments, etc.

• Designated Wild and Scenic Rivers.

• Effluent standards--In many cases, applicable suspended solids/turbidity standards have not been established or recognized. In the past, individual Districts have adopted their own standards (see Table 4); but these standards were not consistent in criteria or stringency. We suggest conferring with the appropriate State environmental agency.

• Location in the proximity of a public water supply intake--Reference 40 CFR 173.

78. Judgment items include both general and site-specific factors. Consideration of the latter must be deferred until a list of specific candidate sites is pared to the extent that reasonably detailed field work is economically feasible. The types of factors to be considered include:

• Conversion of land uses--This can be positive or negative. Loss of forest, farmland, or marshland would probably be considered negative. Conversion of an abandoned quarry or eventual conversion to a shoreline park or building site (possible end uses of a non-reusable disposal site) would be positive impacts.

• Types and numbers of species affected and severity of impacts from locating a disposal site in nesting, breeding, and spawning areas and in migration rest stops--Consult the local office of the U.S. Fish and Wildlife Service (Department of the Interior), sportsmen's groups, birdwatching societies, universities, museums; reference DMRP Work Unit 5B01, "Regional Identification of Species Affected by Dredging/Disposal Operations," completed by the Mobility and Environmental Systems

Table 4

Water Quality Standards for Disposal Area Effluent Adopted for Use by Corps Districts[24]

District	Standard 1973	Standard 1975
Galveston	8 g/l above ambient	8 g/l above ambient
New Orleans	None set	1.5 x ambient concentration
Mobile	None set	50 JTU above ambient
Jacksonville	50 JTU	50 JTU above ambient
Savannah	None set	--
Charleston	None set	--
Wilmington	50 JTU	50 JTU above ambient
Norfolk	13 g/l above ambient	13 g/l above ambient
Philadelphia	8 g/l above ambient	8 g/l above ambient* 4 g/l above ambient**
New York	8 g/l above ambient	1.5 x ambient concentration
Buffalo	50 ppm settleable solids	None set
Detroit	8 g/l above ambient	No standards
Chicago	None set	None set
Sacramento	8 g/l above ambient	6 g/l above ambient
Portland	5 JTU	1.5 x ambient concentration
Seattle	5-10 JTU	5 JTU (State requirement) 5 g/l above ambient (Corps criterion)
Los Angeles	--	None set
San Francisco	--	None set

* Small size areas.

** Large size areas.

Laboratory at WES (the report was published as an internal working document; contact appropriate WES personnel for findings).

- Noise, dust, odor, traffic, safety, mosquito, and aesthetic problems that might affect persons and wildlife near the disposal site or along transport routes from the dredging location and to markets/users and waste disposal sites.

- Location within a prime natural groundwater recharge area--Reference 40 CFR 230. Also, see Paragraph 6 in this report.

REGIONAL TRANSPORTATION NETWORK

79. The regional transport network must serve the transport needs from the reusable facility to markets/users and waste disposal areas.* DM transport was studied in detail in DMRP Work Unit 3B01, "A Study of Dredged Material Transport Systems for Inland Disposal and/or Productive Use Concepts."

80. Transport of DM products and waste is expected to be one of the largest expenses in the overall dredging/disposal operation. Therefore, transport will strongly influence disposal site location and design. The transport investigation should begin in earnest after potential markets/users have been identified and toward the wrap-up stages of the studies of existing and other promising disposal sites. Thus, the transport investigation can focus on modes linking possible disposal areas with potential markets/users and waste disposal sites, rather than try to cover the entire regional network.

81. The transport study should consider both land and water modes. USGS quadrangle maps and aerial photographs will assist in identifying existing transport links--pipeline corridors and truck,

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* Transport to the reusable facility is discussed in DREDGE-INITIAL TRANSPORT SYSTEM in this chapter. Nonreusable disposal sites do not involve transport from the site since, by definition, material is not removed.

rail, and barge routes. But specific, detailed information (e.g., highway load limits that might preclude truck transport of the DM) must be obtained from the appropriate Federal, State, and local agencies and private companies. For example, information on rail rates and the status of various lines and spurs--active, abandoned, and planned additions or deletions--could be obtained from the local office of the Federal Railroad Administration and the appropriate carriers themselves. The District may have to consider the feasibility of constructing rail, highway, barge, and rail links not already existing or planned. A particularly promising but isolated disposal site might be converted to a reusable facility if egress and off-site transport were made available.

82. A District may handle waste transport in either of two ways. The most likely approach would be to contract for the required services. Alternatively, the District could acquire the necessary equipment and staff (e.g., trucks and drivers) to do the job itself. Useful DM-derived products may also be handled similarly. However, a better option would be to induce users to pick up at their own expense material which has been stockpiled on site. The proper inducements (e.g., a lower unit price and a convenient location) can be established in the market/user survey via interviews to determine user capabilities and willingness to pick up material costing various amounts at various distances from their operations. If users will not pick up the material from potential disposal sites, the District must weigh the cost of additional waste disposal (which may also involve transport costs) versus the cost of transporting the material to a location that is sufficiently convenient to induce user participation.

EXISTING DISPOSAL SITES

83. Existing on-land disposal sites, both active and abandoned, are prime candidates for consideration.* Some existing sites are eliminated from consideration immediately for patently obvious reasons. For example, institutional constraints (e.g., zoning laws) might preclude reuse of an abandoned site. For the remaining sites, the following information should be assembled:

- Location relative to: dredging location, potential markets/users, possible waste disposal sites (discussed further in Paragraphs 85-87), regional transport routes feeding potential markets/users and waste disposal areas, and socially and environmentally sensitive and institutionally protected areas.**

- Ingress and egress conditions--Ingress conditions will affect the selection of dredge-initial transport system. Egress conditions might make removal of DM too costly, thus precluding conversion to a reusable disposal site.

- Size--Surface area establishes settling basin performance.*** Note possible room for expansion beyond existing site limits. If confined site, estimate remaining storage volume.

- Condition, dimensions, materials of existing dikes and weirs.

- Type and condition of material previously disposed--Analyze characteristics such as gradation and state of dewatering/consolidation to determine if the material is suitable for use as construction or foundation material during the conversion. This would reduce dependence on off-site borrow areas and need for other measures (e.g., densification techniques) to restore storage volume.

- Topography--Presence of steep slopes might preclude large settling basins.

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* The advantages of using an existing site rather than a new site are discussed in Paragraph 17.

** A useful aid for displaying "relative location" information is the map described in Paragraph 39.

*** Paragraphs 110-117 provide a quick check of minimum area needs.

- Soil and foundation conditions--Poor foundation would limit dike heights or require special construction techniques.

- Hydrology (surface and subsurface)--Groundwater movement toward water supply wells might necessitate containment area liners to prevent contamination by leachate. Occasional flooding might necessitate higher dikes and erosion protection measures.

84. Note that the large number of sites being examined at this stage of the methodology makes it imperative that maximum use be made of existing data to keep costs and manpower requirements down. Most of the listed information could be assembled from maps (e.g., USGS topographic maps, community zoning maps, SCS soil classification maps, etc.), telephone and written inquiries, and some personal interviews. Some information may require brief on-site visits. As a general rule, however, field studies should be minimized until the next phase when the number of sites has been cut.

85. DM waste consists of material that is unusable--either it has unacceptable characteristics (e.g., unsuitable gradation or excessive contaminants) or it is surplus. Waste disposal clearly applies only to reusable disposal sites--a non-reusable site is its own waste disposal site. In rare cases, even a reusable site might not have a waste disposal site associated with it, the rare exception being when all incoming DM is consumed by some productive use.

86. Waste disposal can be on site (i.e., at the reusable disposal facility) if sufficient storage is available. In many cases, however, off-site disposal will be necessary. If the waste is in a dry, stackable form, the task of locating a suitable disposal site is greatly simplified. Prime considerations reduce to storage volume and leachate/runoff control--typical solid waste disposal problems. If the waste is in a slurry form, the task essentially reverts to locating and designing a non-reusable disposal site.

87. Generally, non-reusable disposal sites (other than waste) and reusable sites will be situated adjacent to the water body being dredged. Why? At this stage of the dredging/disposal operation, the DM is usually in a slurry form comprising over 95 percent water by volume.* And it clearly is inefficient and expensive to transport over 19 cubic yards of water for each cubic yard of solids. Reusable sites, however, lessen the waste disposal problem because of volume reductions from dewatering and recovery of usable materials. Thus, it might be practical to transport remaining, unusable solids (which range in consistency from a thick sludge to a stackable form) to remote upland waste disposal sites.**

OTHER SUITABLE DISPOSAL AREAS

88. If the selection of existing disposal sites appears insufficient because of inadequate storage volume or locations inconvenient for promising markets/users, the District must identify other potential disposal sites. Social, environmental, and institutional constraints will immediately eliminate many areas from consideration. In acceptable areas, attention should be directed not only at undeveloped and agricultural sites, but also at "developments" such as gravel pits, quarries, open pit

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* About 69 percent of all maintenance dredging is done by pipeline hydraulic dredges; about 93 percent if hopper dredges are included.[4]

** The District might be assisted in its consideration of upland sites by the results of DMRP task 3B02, Feasibility of Inland Disposal of Dredged Material: Literature Review.

mines, and underground mines which can serve equally well and, in many cases, with a smaller capital investment. Within urban areas, designated floodplain areas offer possibilities.*

89. The information needed to evaluate these sites is generally similar to that required for existing disposal sites and the same considerations regarding waste disposal sites and maximum use of existing data apply.

DREDGE-INITIAL TRANSPORT SYSTEM

90. Selection of dredging equipment and the transport mode which interfaces with the dredging operation (the "initial transport system") can strongly influence the location and design of the disposal site. This selection process, however, was beyond the scope of this study and, therefore, the District must input its own choice of dredge-initial transport system into the methodology. The District has three basic choices: retain the existing plant and work within its capabilities; upgrade the existing plant; or acquire new plant.

91. The District may elect to retain whatever Corps- or privately-owned plant is presently conducting its dredging operations. This alternative has the apparent advantage of economy, since costs with this plant reflect amortization of a capital investment made when equipment was relatively cheap compared to the present-day expense for

* Floodplain regulations often restrict both improvements to existing developments and new floodplain developments. The combination of forced obsolescence and flood insurance costs encourages eventual abandonment of the floodplain to flood-compatible developments and those needing a waterfront location. A DM disposal/processing facility would be a suitable floodplain development provided the dikes didn't cause unacceptable backwater effects.

replacement.* However, the existing plant was designed for a specific mission and, usually, there is limited reserve capability. Thus, the existing plant has built-in constraints that impose compromises or limitations on disposal site location and processing systems. For example, the limited pumping capability of a hydraulic dredge would restrict the radius around the dredging operation within which a disposal site could be located and might preclude consideration of otherwise advantageous sites.

92. The District might retain its present plant, but expand its capabilities. For instance, a pipeline dredge might be upgraded by adding a booster pump and additional pipeline. This could increase the number of accessible disposal sites or improve the efficiency of the operation when disposing at sites on the fringe of the present plant's capability. Thus, this alternative makes good use of the existing capital investment and, with a relatively modest commitment of additional funds, both improves efficiency and expands disposal horizons.

93. A "systems-type" approach to the selection of dredge and initial transport mode offers the best opportunity for maximizing disposal operation efficiency and minimizing adverse environmental impacts. However, major changes in dredge-initial transport plant would require a large capital investment which the District (or the commercial dredging company) might not wish to undertake before the existing plant reaches the end of its economic life.

94. Once the dredge-initial transport plant has been selected, the following measures of performance should be noted for use in locating and designing candidate disposal sites:

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* New plant could be expected to greatly increase amortization costs and would require write-off of the remaining unamortized portion of the original capital investment.

- Transport radius/output trade-off--greater transport distances cut production rates because of increased headlosses for pipeline hydraulic dredges and longer turnaround time for hopper dredges.

- Maximum practicable transport radius--established, for example, by pipeline length for hydraulic pipeline dredges.

- Slurry pumping rate (for hydraulic dredges)--function of dredging depth, pump size, engine power, pipeline length, etc.

- Maximum and average solids concentration (for hydraulic dredges)--a function of height of face, type of cutterhead, etc.

- Maximum and average solids production (for mechanical dredges)--a function of dredging depth, bucket size, etc.

95. The San Francisco District has published a report which includes a computerized mathematical dredging-transport simulation model to compare and optimize alternative dredging-initial transport systems.[25] This model would be a useful tool to assist a District in deciding whether to stay with or improve its existing plant or to select entirely new plant. The model inputs capabilities of various dredging and transporting equipment and dredging and disposal locations and identifies the least-cost system. Thus, the District might input any or all of the following alternatives into the model:

- Existing dredging locations and present plant capabilities plus possible disposal sites within the range dictated by these capabilities.

- Existing dredging locations and present plant with upgraded capabilities plus possible disposal sites within the increased range of the improved plant.

- Existing dredging locations and open selection of dredging-initial transport equipment plus possible disposal sites within reasonable range.

96. Results from the model must be used with caution in this methodology because the limited disposal concept that was used excludes important economic factors for reusable disposal sites. The San Francisco District assumed disposal was permanent; material was not removed

for use or final disposal elsewhere after processing. Thus, consideration was limited to non-reusable disposal sites. Processing of the dredged material consisted of settling and drying in settling basins; chemical and/or mechanical treatments were optional to speed the process. After the design life of the disposal site was over, the site could be built upon or used for recreational or agricultural purposes. To apply the San Francisco model to reusable sites would require modifications to cover costs for equipment to process the DM to user specifications plus site-to-market and site-to-waste disposal area access and transport, less any revenues that might be realized from marketing usable materials.

CHAPTER 4

PHASE II

SELECTION OF CANDIDATE DISPOSAL SITES/SYSTEMS

OVERVIEW

97. The goal of Phase II is a list of the most promising candidate sites and multisite systems capable of handling the dredging program being studied (be it only a single dredging operation or the District's entire dredging program). The benefits of paring the list of candidates to only those deserving of serious study are savings of time and money in subsequent phases. This section of the methodology utilizes the information collected in Phase I to:

- Combine individual disposal sites into alternative multisite systems capable of handling the projected volume of DM.
- Eliminate unsuitable and inferior sites (and the multisite systems of which they are a part) from the list of existing and potential disposal sites identified in Phase I.
- Gather site-specific information for sites passing the elimination process to permit preliminary site designs and cost estimates in Phase III.

98. We suggest that initial consideration be given to maximizing the role of reusable disposal sites. This is in keeping with the philosophy that, in the long run, reusable sites are the best solution to problems associated with DM disposal. Dredging locations that cannot be served by reusable sites for some reason can be assigned to non-reusable disposal sites. A typical multisite disposal system will consist of a mix of reusable and non-reusable sites.

99. The elimination process is, in effect, a two-stage screening process. During the primary screening stage, the sites are examined in light of "yes/no" constraints and obvious, gross shortcomings which

preclude a site from further consideration. During the secondary screening stage, the relative advantages and disadvantages of the remaining sites are compared, the sites are roughly ranked, and poorer sites are eliminated.

100. Combining individual disposal sites into alternative multisite disposal systems is a requisite to the elimination process. Why? Generally a single disposal site cannot be expected to handle the needs of the entire dredging program. The site might have insufficient storage capability or the dredge-initial transport system might not be able to reach a single disposal site from all the dredging locations. The suitability of a disposal site candidate depends on the particular multisite system of which it is a part. A candidate might be fine as a reusable site in a system comprising a small number of disposal sites, each handling a large volume of DM. But it might not be suitable as a non-reusable site should the large DM volume exceed its storage capacity. This same site might also be considered for inclusion within other systems, for example, one comprising a greater number of disposal sites. In this latter system., the disposal site might serve very well as a non-reusable site because it would be responsible for less DM, but be unsuitable as a reusable site because the small quantity of DM might not warrant high processing costs. In some cases, a disposal site can be eliminated entirely; either it is redundant (other sites can handle the disposal assignments more efficiently and with fewer adverse impacts) or it is simply unable to handle its share of the disposal program in either reusable or non-reusable configuration.

101. In this fashion, the District combines individual disposal sites into alternative systems capable of handling the disposal program and assigns corresponding DM quantities and characteristics, initial and off-site transport modes and distances, markets/users, waste disposal sites, etc. We recommend displaying the information for each multisite

system on a separate map such as that described in Paragraph 39. The number of alternative multisite systems should be kept reasonably low--say no more than a dozen if possible.

PRIMARY SCREENING

102. The primary screening process and the selection of multisite systems go essentially hand in hand. As the District examines each individual disposal site in terms of how it might fit into alternative systems, constraints and gross shortcomings become readily apparent. If a multisite system incurs a "gap" in coverage as a result of eliminating an unsuitable disposal site,* then the system itself becomes nonviable (unresponsive to the dredging program's needs) and is dropped from contention.

103. Constraints include:

- Institutional, environmental, and social.
- Dredge-initial transport system.
- Off-site transport.
- Area/volume.

Note that the market/user situation is not a constraining factor in deciding a site's suitability for reusable (and, of course, nonreusable) disposal.** Even if productive use of the DM is not possible--

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* Although this site might be perfectly satisfactory in another system, say because it need handle less DM.

** The market/user situation is more important in selecting the kind of processing to use.

e.g., if the DM characteristics are unsatisfactory--a reusable operation might still be desirable and certainly is possible; all the material would be removed to a waste disposal area.

Institutional, Environmental, and Social

104. Institutional, environmental, and social constraints identified in Paragraph 77 are usually so evident as to make their influence felt earlier in the methodology, when identifying existing disposal sites and other areas worthy of any consideration. Under certain circumstances, factors which otherwise are not constraints can assume that stature:

- Destroying a locally rare or unique feature can meet with strong opposition. Examples include: trees lining the riverbank in an otherwise treeless area; a stand of unusually majestic oaks; a building, covered bridge, or other structure of local historic interest.

- Because of DM's bad image, locations immediately adjacent to residential areas are probably untenable. Public reaction will be decidedly negative in the face of possible safety hazards for inquisitive youngsters and alleged odor, dust, noise, mosquito, and aesthetic problems.

- The growing concern for wetlands preservation as expressed in the P.L. 92-500 implementation guidelines (see Paragraph 9) may place wetlands into a generally "untouchable" category.

Dredge-Initial Transport System

105. Because of the substantial investment in properly designed reusable and non-reusable disposal sites, it is advantageous to have each site serve as many dredging locations as possible. However, the capabiliities of the selected dredge-initial transport plant define the geographic limits of the disposal site search. If dredging operations are widely spaced, there may not be a single central area within reach. A pipeline dredge, for example, has only so many feet of pontoon line and shorepipe. Even in cases where transport radii do overlap (see Figure [illegible]), the common area might not be suitable for a disposal site, thereby necessitating two disposal facilities.

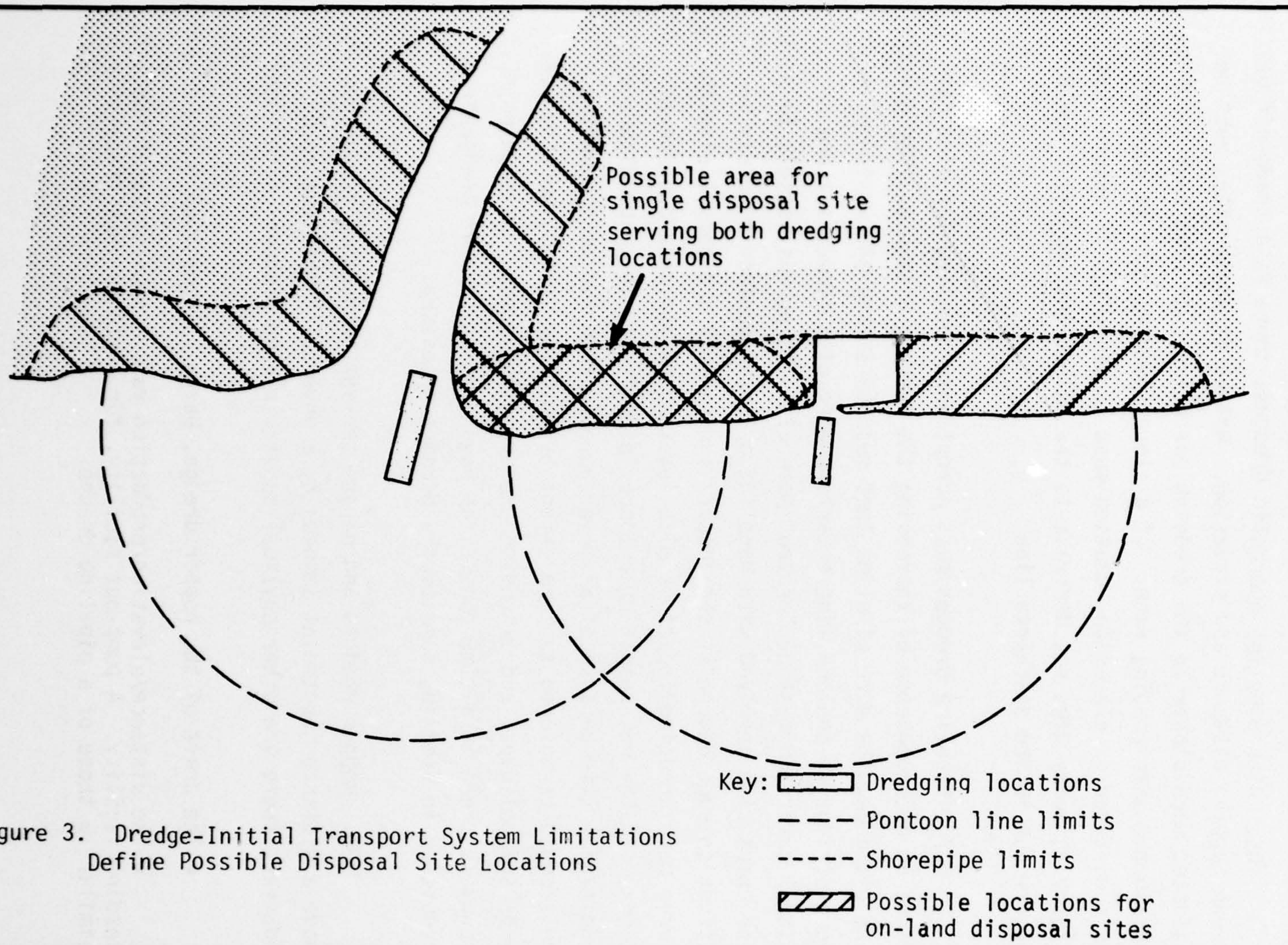

Figure 3. Dredge-Initial Transport System Limitations Define Possible Disposal Site Locations

106. With pipeline hydraulic dredges, there is a trade-off between pumping distance and elevation. Upland disposal sites must be situated much closer to the dredging operation than riverbank sites to retain the same pumping rate. If a slower pumping rate is accepted to gain distance or elevation, caution must be exercised to ensure that the slurry velocity does not decrease to the extent that material would settle out in the discharge line.

107. Pipeline dredges must accept more downtime for pipe handling as a consequence of increasing the pumping distance. The greater the distance, the more pipeline that must be strung and unstrung. Also, long strings of pontoon line interfere more with commercial and recreational craft and must be "broken" more often to permit vessels to pass. The extra time involved with handling a longer pontoon line may be offset to some degree if the longer line permits a disposal site to serve more dredging locations with fewer setup and takedown operations. If the net result of a longer pipeline is the expenditure of additional time because of a slower pumping rate and more downtime, this could be covered to some extent by multiple shifts, working weekends and holidays, and extending the dredging season. At some point, however, there is a time constraint beyond which another dredge or a reduction in dredging commitments becomes necessary.

108. Hopper dredges and barges serving mechanical dredges do not have a distance constraint imposed by a physical "umbilical cord." However, there are other physical constraints on disposal site location:

- The draft of the hopper dredge, barge, or pushboat.
- The distance/elevation/production rate capabilities of the offloading facility. A pump-out facility, for instance, has trade-offs similar to those of a pipeline dredge.

Time-of-travel is an equally important factor constraining the distance between dredging and disposal operation. Excessive barge turnaround time would have essentially the same impact as excessive pipe handling time (see Paragraph 107).

Off-Site Transport

109. Transport mode must be matched to delivery requirements for both useful products and waste materials leaving the reusable site. Once the transport mode is selected, the right-of-way should be laid out avoiding protected areas (e.g., a wildlife refuge). In some cases, egress will obviously be impracticably costly--because of surrounding developments, steep topography, poor foundation conditions, or remoteness--so as to preclude development of a reusable site unless on-site use and waste storage are adequate.

Area/Volume

110. Storage volume becomes a major concern when waste must be permanently interred on site as it is with all non-reusable and some reusable sites. On-site waste disposal is differentiated from on-site productive use; however, in some situations, the ultimate fate of the material is essentially the same. For instance, stackable waste --e.g., coarse materials such as sand or gravel--could be incorporated into aesthetic mounds along the perimeter of the facility. Depending on the extent of the mounds and the quantity of waste generated annually, this type of disposal could provide several years of relief. Figure 4 illustrates example storage volumes at hypothetical facilities. Based on the assumptions in this figure, mounds around a 40-acre facility would handle a waste output of 100,000 cubic yards per year for less than 6 years; mounds around a 20-acre facility would handle this same output for little more than 4 years. We conclude that in most cases this type of waste storage is a short-term answer at best.

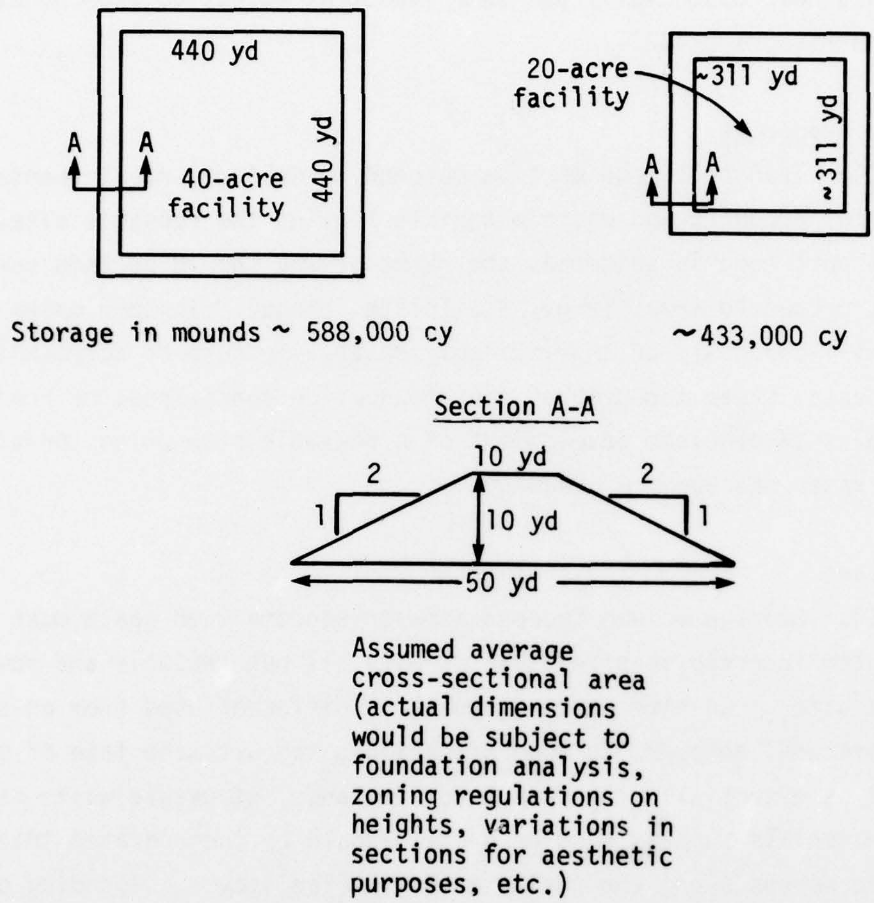

Figure 4. Waste Storage Potential of Aesthetic Mounds Around Reusable Disposal Sites

111. Waste in "sludge" or slurry form presents a more difficult disposal dilemma because the waste must be confined in containment basins. For illustrative purposes, assume:

- Annual waste output at the disposal site is 100,000 cubic yards of slurry.
- Storage is needed for a 20-year period.
- Foundation conditions restrict dike height to 30 feet and storage depth to 28 feet to allow some freeboard.

Then, the area of the containment basin must be over 44 acres. When this figure is combined with area requirements for processing basins, dikes, etc., the site size becomes so large as to eliminate many otherwise suitable locations. This suggests the advantage of a reusable site with separate facilities for processing and waste disposal and clearly illustrates why non-reusable disposal causes such a high attrition rate of prime on-land disposal sites.

112. The area required for processing facilities is essentially nil for a non-reusable disposal site with nonslurry input; long-term storage volume is the critical factor. A reusable site handling a nonslurry input and whose output is unclassified (i.e., not separated by size) can be treated in a similar fashion; the largest area demand is from storage for any on-site waste disposal or stockpile of useful material.

113. Reusable sites with a classified output and both reusable and non-reusable sites with a slurry input require a more complex computation to estimate the area of processing facilities. Because of their simplicity and relatively low capital and O&M costs, settling basins will be used wherever possible to remove suspended solids. A DM disposal site designed to meet applicable effluent standards will usually comprise an Initial Solids Removal (ISR) facility (including an

ISR basin) and a final solids removal (FSR) facility (which may also include a settling basin).* The ISR facility reduces the solids concentration to an optimum value for subsequent flocculation of colloidal particulates in the FSR system. The ISR basin is the largest single piece of <u>processing</u> "equipment" in the entire facility. Note, however, that <u>nonprocessing</u> area requirements (for stockpiles or waste disposal) could be considerably larger than the ISR basin. Also, remember that an ISR basin at a non-reusable disposal site is used for both solids removal and final solids storage. Whichever of the two uses demands the bigger area establishes the ISR basin's minimum area.

114. The approximate area of the ISR basin can be calculated from a simple formula based on the ideal settling theory:

$$A = 785.5\ FQ/D^2 \qquad \text{Equation 1}$$

where: A = Settling basin surface area, ft^2
F = Adjustment factor (see discussion)
Q = Influent rate, gpm
D = Diameter of smallest particle that must be removed, μm

The area value derived from this formula is only an approximation and should not be used for design purposes. The area calculated is always smaller than that actually needed to meet any given effluent standard; therefore, we recommend applying an adjustment factor of 1.2. Q is the rate at which flow will enter the processing facility--for example, the pumping rate from a holding basin used to attenuate peak flows from a hopper dredge pump-out operation.** D is read off the DM gradation curve using the solids retention value computed from:

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* Disposal site configurations are discussed in detail in Chapters 5-7.

** The holding basin concept is described in Chapters 5 and 6.

$$R = 100\,[1 - (100/C_1 - 1)/(1000/C_2 - 1)]$$ Equation 2 (See Figure 5)

where: R = Solids retention, %
C_1 = Influent solids concentration by dry weight, %
C_2 = Effluent solids concentration, g/l

If the primary dredge (which removes the in situ DM) discharges directly into the ISR basin, C_1 is the maximum value that might reasonably be expected from this dredge. If slurry from a hopper dredge pump-out operation is first pumped into a holding basin and then into the ISR basin, C_1 must be that average solids concentration achieved during hopper dredge pump-out (assuming no water is added to or lost from the holding basin).* The C_2 value should yield economical flocculation in the FSR system.** If C_1 is given in percent solids by volume, this can be converted to percent by dry weight via Equation 3:

$$C = V \times SG/[1 + .01V\,(SG - 1)]$$ Equation 3
or $C = V \times SG/M$

where: C = Percent solids by dry weight, %
V = Percent solids by volume, %
SG = Solids specific gravity
M = Slurry specific gravity

given: V = 4% (from dredge)
SG = 2.65

then: C = 9.9%

---

* See Chapter 7 for further discussion. Variations in solids concentrations when redredging the holding basin's sediments (and therefore in the C_1 of the ISR basin) will cause C_2 to vary. Since C_2 of the ISR basin becomes C_1 of the FSR facility, the rate of flocculant feed will be varied accordingly to ensure a uniform effluent quality.

** Flocculation is discussed in Chapters 5 and 7. The District should review the results of DMRP Work Units 6B07, "Flocculation as a Means for Water-Quality Improvement from Disposal of Dredged Material in Confined Areas," and 6C04, "Assessment of Chemical Flocculants and Friction-Reducing Agents for Application in Dredging and Dredged Material Disposal," for information regarding suitable solids concentrations for economical flocculation treatment by various flocculating agents.

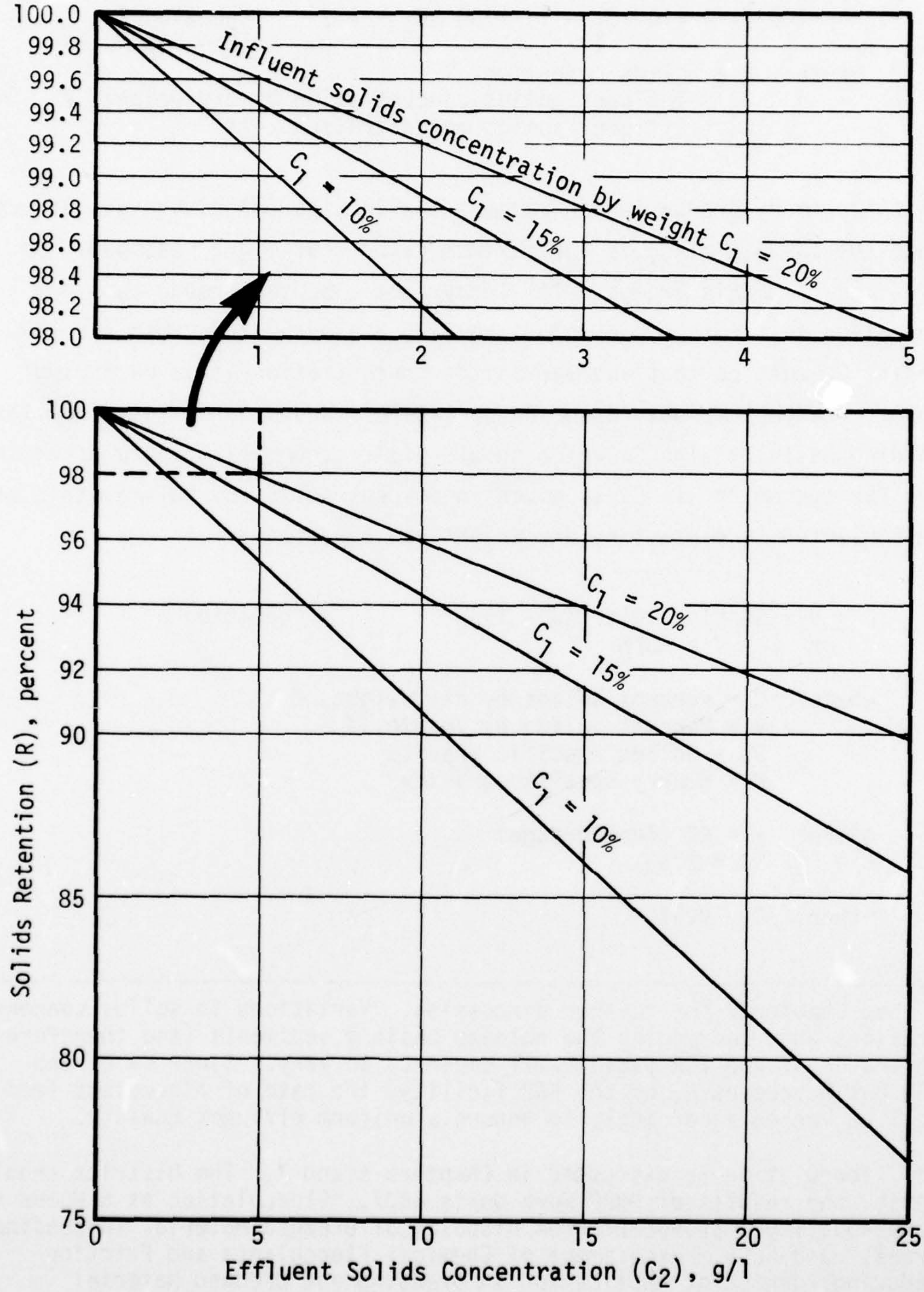

Figure 5. Solids Retention Required to Meet Specified Effluent Standards Given Influent Solids Concentration

Caution must be exercised to ensure that percent solids by volume means solids, not in situ material (which includes both solids and voids). If the "solids" concentration is given in terms of percent of slurry volume which is material, use Equation 4 to find solids concentration by dry weight:

$$C = \frac{100\ V_m \times SG \times (B - 1000)}{(SG - 1)\ [10^5 + V_m\ (B - 1000)]} \qquad \text{Equation 4}$$

where: V_m = Percent of slurry volume which is material, %
B = Bulk density of material, g/l

given: V_m = 20% (from dredge)
B = 1600 g/l
SG = 2.65

then: C = 17.2%

115. The particle size (D) corresponding to the computed R value is read off the gradation curve of the incoming DM. If D is not in the colloidal range,* calculate the ISR basin area via the given equation. If D is in the colloidal range, the solids retention in the ISR will not be sufficient to meet the C_2 value for optimum flocculation. Therefore, the selected flocculant must be used in greater than optimum quantities or a different flocculant must be selected, one which can optimally handle a higher solids concentration.

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* Colloidal matter consists of particles too fine-grained for gravity settling. There is disagreement among authorities as to the dividing line between colloidal and noncolloidal matter. Reference 26 states that "particles in the <2μ range are colloidal"; Reference 24 says: "Submicron particles constitute a large portion... of the bottom sediments that are candidates for dredging.... Particles of this size, unless they aggregate to form larger equivalent particles, will not settle out of suspension, even with long detention time...." In this report, we adopt 2 μm in all examples as the threshold value for colloidal matter.

116. The District should reject outright disposal sites which do not have room for an ISR basin of the size calculated. If other area requirements can be estimated at this time (e.g., on-site waste storage, product stockpiles, etc.), these should be added to the ISR basin area to provide a more accurate minimum area requirement.

117. Example

given:	C_1 (from the dredge)	=	10%
	C_2 (for economical flocculation)	=	20 g/l
	Q (from the dredge)	=	16,000 gpm
	Gradation curve of incoming solids shown in Figure 6		
then:	R (from Equation 2 or Figure 5)	=	81.6%
	D (from gradation curve)	=	approximately 6 μm
	A (from Equation 1)	=	419,000 ft^2
		=	9.6 acres, say 10 acres

Other Constraints

118. Other apparent constraining factors generally are covered by the above categories. Foundation (geotechnical) conditions, for example, might limit dike heights, hence available storage. Site topography might make egress impossibly expensive or preclude large settling basins.

SECONDARY SCREENING

119. The candidate sites remaining after the primary screening stage are all "viable," i.e., capable of functioning satisfactorily at a not unreasonable cost (according to the information thus far available). Any further eliminations at this point must be done on a relative basis, wherein sites that cost substantially more or cause significantly worse environmental/social impacts are discarded. Relative advantages and disadvantages of the remaining sites are compared and the sites categorized as "good," "fair," and "poor." "Poor" sites (and possibly

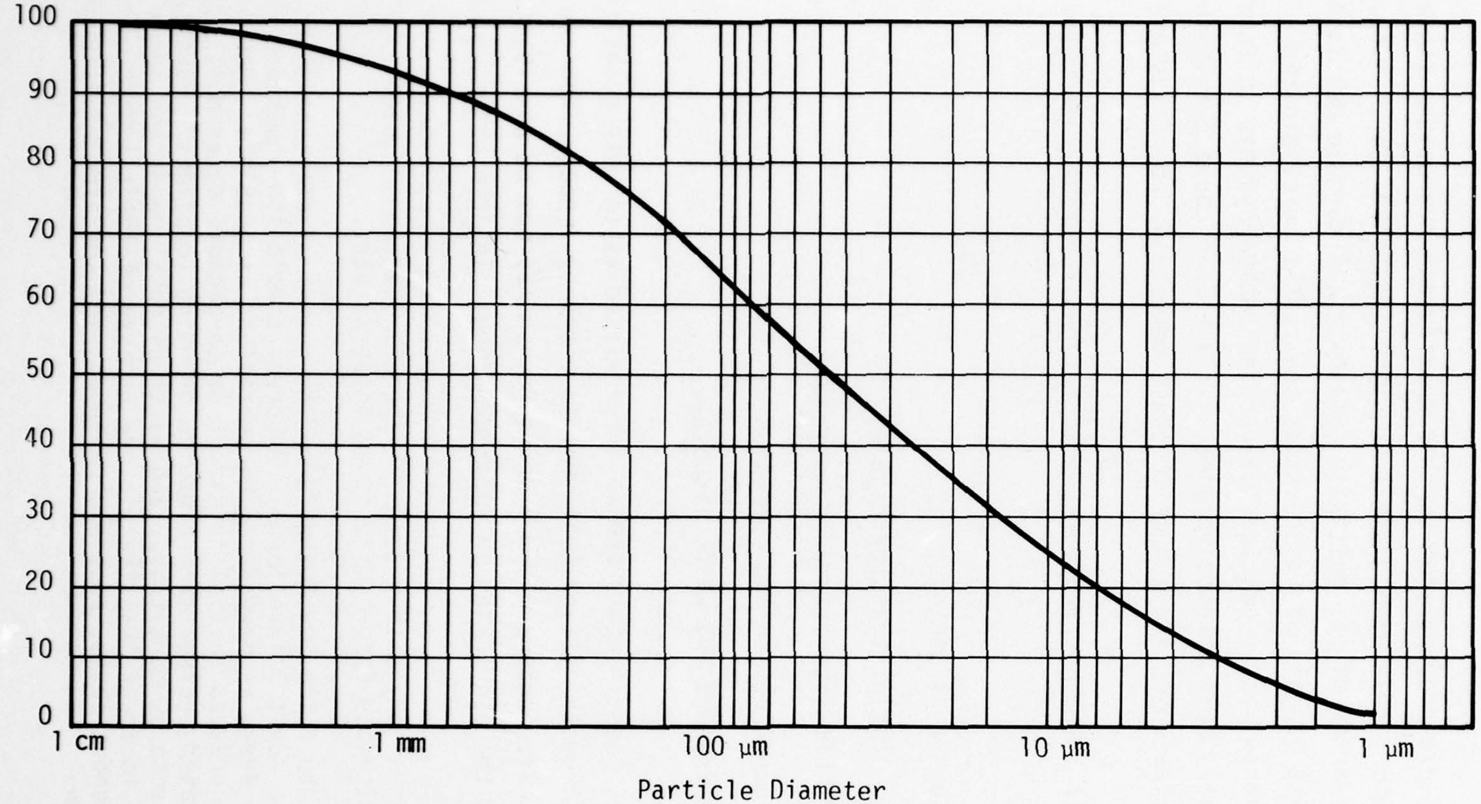

Figure 6. Incoming Gradation Curve for Example of Quick Estimate of Area of Initial Solids Removal Basin

"fair" sites) are dropped from further consideration provided the elimination of any single site doesn't create a "universal gap," i.e., a gap in the coverage of all multisite systems.* If certain multisite systems consist largely of "poor" sites that can't be eliminated without creating universal gaps, consider discarding entire systems in favor of other, generally more attractive ones. This action could eliminate still more sites which are unique to these generally "poor" systems.

120. The general areas of consideration essentially narrow down to:

- Environmental/social.
- Dredge-initial transport system.
- Egress-off-site transport system.
- Site construction and operation.
- Markets/users and waste disposal.

Unfortunately, these factors are so interrelated as to make quantitative assessment extremely difficult.** Unless costs or impacts from one or more of the above factors clearly dominate, it may not be possible to reliably rank the candidates on judgment alone. In some cases, costs

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* Elimination of any site results in the elimination of multisite systems of which the "poor" site is an integral part.

** Consider the following: the fewer the number of disposal sites, the smaller the capital investment. Apparent conclusion--have each disposal site serve as many dredging operations as possible. However, this scheme increases initial transport costs because sites must be centrally located, rather than close to dredging locations. Furthermore, the effects of market/user and waste disposal needs and locations must be factored into the picture because of their impact on off-site transport costs, possible revenues, and the type of disposal site operation.

and impacts will have been quantified (albeit crudely) during the preliminary screening. In many cases, however, it will be necessary to proceed to the next phase of the methodology wherein preliminary cost estimates for the disposal sites are made.

Environmental/Social

121. Degradation of legally unprotected, but environmentally- and socially-sensitive areas must be judged by the District as to comparative severity. Impacts from construction and operation of the disposal site, transport facilities, and waste disposal area include possible permanent conversion of land use, dust, noise, odors, greater accident incidence (from increased rail, truck, and/or barge traffic), etc. Mitigative effects should also be considered, for instance, the possible long-term savings of wetlands or other wildlife habitat.

122. As discussed in Paragraphs 105-108, there are trade-offs in terms of distance, elevation, transport rate, and time. The treatment in the primary screening is to determine constraints imposed by these factors. In the secondary screening stage, we stay within these constraints and use comparative costs to measure the relative advantage of one site over another. Cost essentially integrates the effects of the various trade-offs into a single factor. Note, however, that it is incorrect to isolate and optimize dredge-initial transport costs alone. Consider two sites, one situated adjacent to the dredging location and one some distance away. DM delivery to the former will be more economical, but the latter might compensate by being cheaper to convert to reusability and more accessible to off-site transport to markets/users and waste disposal areas.

Egress-Off-Site Transport System

123. Costs for physical improvements depend in part on how convenient the disposal site, market/user, and waste disposal area are

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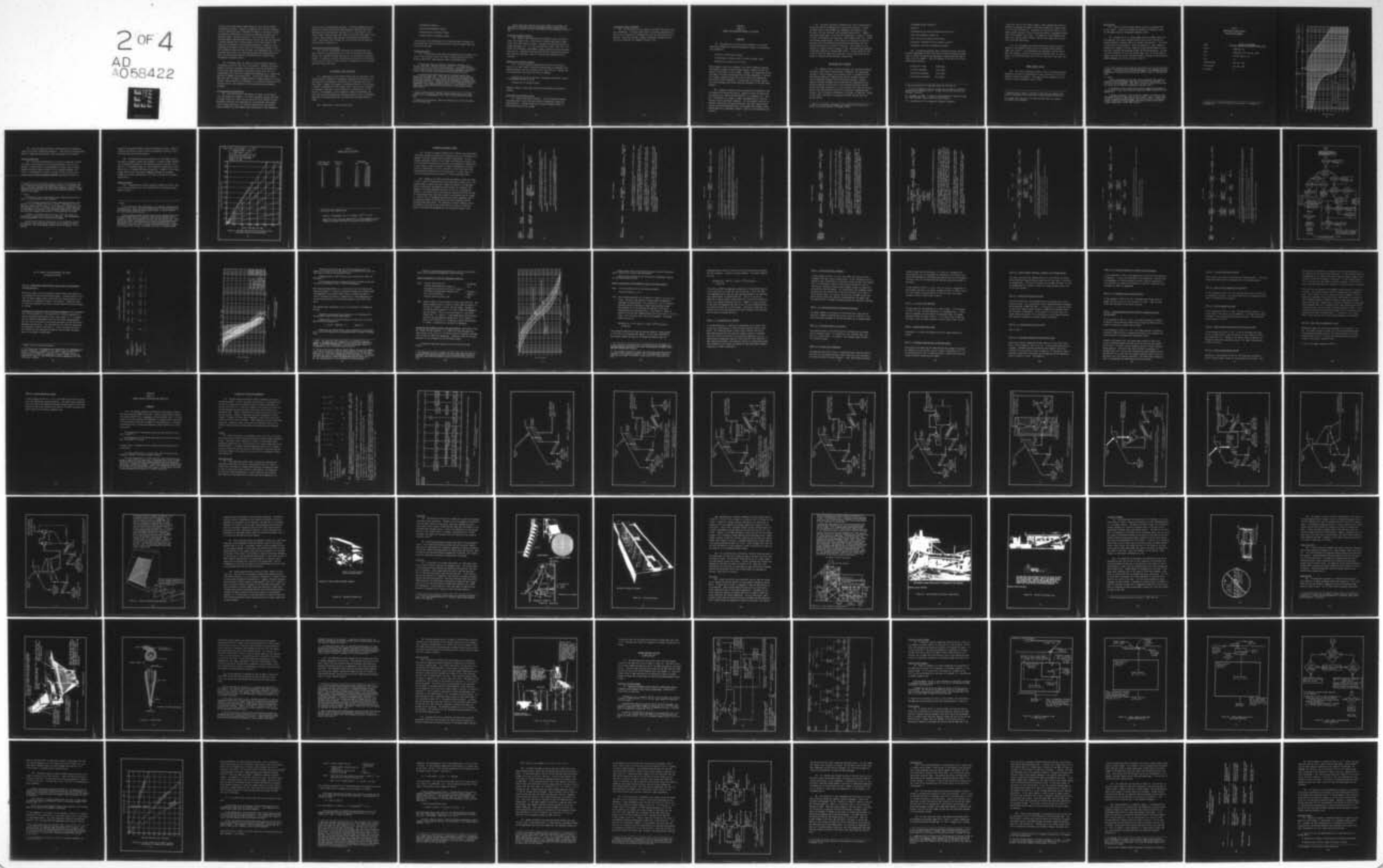

relative to an established suitable branch of the existing regional transportation network. However, convenience isn't the only consideration; as the District has to consider the impact of its entry into the raw materials marketplace, so it must also consider the impact of its transport needs. An annual output of 1 million cubic yards of DM-derived products and waste would require 115 rail cars per day (assuming a 250-day workyear and a typical capacity of 35 cubic yards) or 400 trucks per day (based on a 10-cubic yard capacity). Obviously, this magnitude of increase in daily traffic will have major impacts on rail car availability, wear and tear on roads, fuel consumption, etc. If the projected extra traffic will overload the existing transportation network, the District must consider the feasibility of constructing a supplemental transport system.

124. Transport costs are likely to be more important than one-time capital costs over the life of the project. Although the District shouldn't isolate on transport costs alone, it can be concluded that sites farther from markets/users and waste disposal areas are at a disadvantage unless they offer compensating advantages (e.g., cheaper DM delivery or cheaper site construction). The District should consult DMRP task 3B01, "A Study of Dredged Material Transport Systems for Inland Disposal and/or Productive Use Concepts," for a detailed discussion of DM transport and for cost estimates for various handling and transport equipment.

Site Construction and Operation

125. Site construction costs depend, of course, on the type of site--non-reusable or reusable. The former generally requires more area and bigger dikes; the latter requires egress-off-site transport routes. Foundation conditions and topography are also important. Poor foundations increase dike costs, for instance, because extra dike material might be needed (for displacement-type construction) or the foundation

material must be excavated and replaced. A rolling topography could be expensive to grade for multiacre settling basins and other facilities. Operating costs also depend on the type of site. Non-reusable sites involve fewer processes, hence cost less; but reusable sites have a long lifespan, hence dispense with the need for constructing replacement sites. Preliminary cost estimates for site construction and operation are discussed in Chapters 5-7.

Markets/Users and Waste Disposal

126. Most of the important influences from markets/users and waste disposal are covered under one or more of the factors discussed above--e.g., transport distance and type of site and specific processes needed. In addition, possible revenues must be brought into the picture since they will offset, at least in part, the added costs for processing the DM to market/user specs.

SITE-SPECIFIC DATA COLLECTION

127. Preparatory to preliminary designs and cost estimates, site-specific data are required to supplement information collected thus far. Field work will be necessary, particularly for candidates lacking reliable data. However, the number of candidates might still be too great to permit a comprehensive field program from a time and cost standpoint. We recommend a walk-over of each candidate by representatives of the District's environmental, soils-foundation, hydraulics-hydrology, design, and construction-operations (dredging program) units to supplement data with first-hand observations and impressions by experienced personnel.

128. Gather data in the following areas:

- Engineering factors.
- Social/environmental setting.
- Markets/users and waste disposal.
- Egress-off-site transport system.

In some cases, this information will already have been developed on a preliminary basis and this opportunity can be used to double check the accuracy of the data.

Engineering Factors

129. The following items should be examined for the disposal site itself, waste disposal areas, and routes linking disposal sites with dredging operations, waste disposal areas, and markets/users:

- Topography--Note any important topographic features (e.g., gullies) that aren't shown on the maps on hand. Try to define small contour intervals (as fine as 2-foot contours, if possible), but confine any surveying to those sites where no reliable topographic information exists.* Note surface runoff patterns that would be disrupted.

- Geotechnology/geohydrology--Acquire available boring logs, bedrock and soil maps, etc. Field work at especially promising candidates might include a test pit to check for construction materials and foundation conditions.** Determine borrow area material characteristics and estimate unit costs. Locate the water table; determine direction of groundwater flow; establish whether the site is in a recharge or discharge area; locate nearby wells that might be threatened by contaminated leachate.

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* Because of the expense, wherever possible defer the use of survey crews or aerial photogrammetry until final site selections have been made.

** Because of the expenses, defer test borings until final site selections have been made.

- Unit land costs--Consult with local realtors to estimate unit land costs at disposal sites, waste disposal areas, borrow sites (if they must be acquired outright), and egress-off-site transport rights-of-way.

Social/Environmental Setting

130. Conduct field examinations of disposal, waste, and borrow sites and transport links. Note signs of wildlife and types of vegetative cover that would be cleared. Consider the relative locations of nearby residences, etc., in light of prevailing winds, sight lines, etc. Confer with residents, environmental groups, university faculty studying the area, etc. Determine the applicable effluent standards and ambient water quality conditions; check for favorable and unfavorable local variances.

Markets/Users and Waste Disposal

131. For each reusable candidate and the multisite systems of which it is a part, adopt a tentative program based on estimated sales/donations/wastes over the projected life of the facility. Consider the two extreme cases (see below) and cases in between:

- Market/use as much of the DM as reasonably practicable; dispose of the unusable portion as waste.

- Dispose of all the DM as waste.

Identify product or waste specs that must be met under the tentative programs.

Egress-Off-Site Transport System

132. Examine the egress situation. For each tentative program (discussed above), select the best means of transporting usable and waste materials. Consider tying into existing transport systems or constructing entirely new systems.

Site-Specific Data Collection

133. The site-specific data should be collated with other available information. This data should then be plotted as appropriate on maps (such as described in Paragraph 39) with the remaining multisite systems. These maps provide a compact information package for each multisite system and its component disposal sites.

CHAPTER 5

PHASE III

PROCESS SELECTION/PRELIMINARY SITE DESIGN

OVERVIEW

134. The objective of the next three chapters is to provide clear-cut procedures for selecting economical disposal site processes and equipment to:

- Ensure a satisfactory effluent.
- Consolidate or remove solids to restore storage volume.
- Beneficiate solids for use or sale.

These chapters focus on the disposal site itself; dredging, handling, and transport systems and the ultimate (waste) disposal site are not covered in like detail in this report. However, the methodology assists the reader in making informed decisions on these components of an overall disposal system by discussing critical factors and identifying particularly useful references. In most cases, an ultimate disposal site can be designed and costed using the procedures in the next three chapters.

135. Chapter 5 presents the basic approach and assumptions used in disposal site design and costing. Chapter 6 covers the separation and processing of coarser-grained materials in a reusable site. Chapter 7 concentrates on systems to remove suspended material from the effluent to meet applicable standards. For non-reusable sites and for reusable sites with an unclassified output, this means removing both coarse- and fine-grained materials; for reusable sites wherein coarse-grained material is separated, Chapter 7 applies to the remaining fine fraction.

136. The latest available information was used in developing the design and costing recommendations in these three chapters. Sources included reports from the DMRP and independent investigators, plus brochures from and interviews with equipment manufacturers. However, the reader should keep in mind that the methodology is subject to change as other investigations are completed. Some problem areas (e.g., solids and effluent contamination, solids removal of extremely fine-grained particles, and solids dewatering/consolidation techniques) are not conclusively resolved in current literature. These subjects are addressed in a broad, tentative manner at this time pending the completion of pertinent ongoing or proposed DMRP studies. These studies are identified so that the reader can review their results when published to update or complete the methodology as appropriate.

PRELIMINARY COST ESTIMATES

137. Chapters 6 and 7 provide procedures for estimating disposal site costs, both capital and operation, maintenance, and replacement (O,M,&R).* These estimates are extremely useful in conceptual design and planning studies for comparing the relative economic posture of various individual disposal sites and multisite systems. However, these preliminary estimates are no substitute for comprehensive cost analyses prepared by the District's Cost Estimating Section from detailed site plans (see Phase V). Also, disposal site costs are only one facet of the total economic picture for the overall dredging/disposal program. The following are indicative of the types of items not "costed" in this report, but whose costs <u>must</u> be factored into the decision-making process:

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* Specific inclusions, exclusions, and assumptions are discussed in detail in the cost sections of Chapters 6 and 7.

- Dredging-initial transport.*
- Land.**
- DM handling (on- and off-loading facilities).***
- Off-site transport systems.***
- On- and off-site stockpile facilities.
- Aesthetic treatments for the disposal site.****
- Revenues from sales of DM-derived products.

138. In preparing detailed costs, specifically those involving periodic replacement of plant, the District should consider the useful lives of various structures and equipment as specified by EPA Regulations, Title 40, Chapter 1, Part 35, Appendix A (38 CFR 174) for cost-effectiveness analyses:

• Structural items	30-50 years
• Process equipment	15-30 years
• Auxiliary equipment	10-15 years
• Electrical equipment	8-10 years

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* See the discussion in Paragraphs 90-96 and Reference 25.

** A value of $2000/acre has been assumed for preliminary estimates of system costs in Chapters 6 and 7. A more precise value could be substituted if desired.

*** See DMRP task 3B01, "A Study of Dredged Material Transport Systems for Inland Disposal and/or Productive Use Concepts."

**** See Reference 27 for suggested landscape treatments.

It was felt that in this report, however, these computations would unnecessarily encumber the reader in the many examples of economic analysis of various alternatives. Therefore, the preliminary costs in this report assume the useful life of the various pieces of equipment matches that of the disposal site itself. The examples in the methodology do adopt the 7 percent annual interest rate for cost comparisons as specified by the EPA regulations.

139. Cost estimates are based on 1976 price levels and may be updated in the standard fashion using the Engineering News Record's (ENR) cost indices.* Cost adjustments for geographic location can be done, for example, by adding the appropriate freight costs for equipment** and estimating other costs (such as dike costs) from local unit costs.

RANGES/EXAMPLE VALUES

140. This section discusses ranges of some of the more important parameters and specific representative values selected for use in subsequent illustrative examples. The ranges are not intended to be all-inclusive; they do encompass typical values.

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* Detailed costs in Phase V (Chapter 9) should not be indexed; they should be developed from current quotes from equipment manufacturers.

** Freight costs are one of the items excluded from this report's preliminary cost estimates.

Particle Size

141. Table 5 defines the descriptive particle size ranges used in this report. Figure 7 also shows the envelope of gradation curves for DM samples taken at maintenance dredging sites.*

142. Although 75 μm is a more common division between coarse and fine material, this report defines material ⩾150 μm (No. 100 mesh) as "coarse material"; material <150 μm is termed "fine material." The reason for this particular breakpoint: With rare exceptions, "spec products" produced by a reusable site will comprise coarser-grained materials that have been recovered and processed to meet the desired gradation. The use of 150 μm instead of 75 μm as the design lower limit for coarse material reduces the size and cost of the coarse material separation and processing (CMSP) equipment by a factor of three or four.**

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* Note: The envelope shown comprises gradation curves based on dispersed samples.[24] The effect of using dispersed samples is to overemphasize the percentage of fine-grained particles, particularly those in the submicron range.

** Notes:

- Small percentages of the <150- to 75-μm material that might be required in the spec product would be retained even with equipment designed for 150-μm retention. (See STEP 1 in key to Figure 9 for an example calculation of ASTM Fine Aggregate production rate.)

- Exceptions to the 150-μm coarse material separation breakpoint include three of ten coarse material processing (CMSP) alternatives (see Chapter 6).

- Another exception is the relatively uncommon case where a high percentage of DM is in the <150- to >75-μm range. Here, it might be desirable to design the CMSP equipment for 75-μm retention to reduce the surface loading and storage volume requirements on the solids removal systems "downstream" of the CMSP facility.

Table 5

Definition of Descriptive

Particle Size Ranges

Term	Particle Size Range Particle Diameter, micrometres (Mesh Size)
Gravel	>2360 (No. 8)
Sand	<2360 (No. 8) to >75 (No. 200)
Silt	<75 (No. 200) to >10
Clay	<10
Coarse-grained	⩾150 (No. 100)
Fine-grained	<150 (No. 100)
Colloidal*	⩽2

* *Adoption of a colloidal threshold is discussed in a footnote to* Paragraph 115.

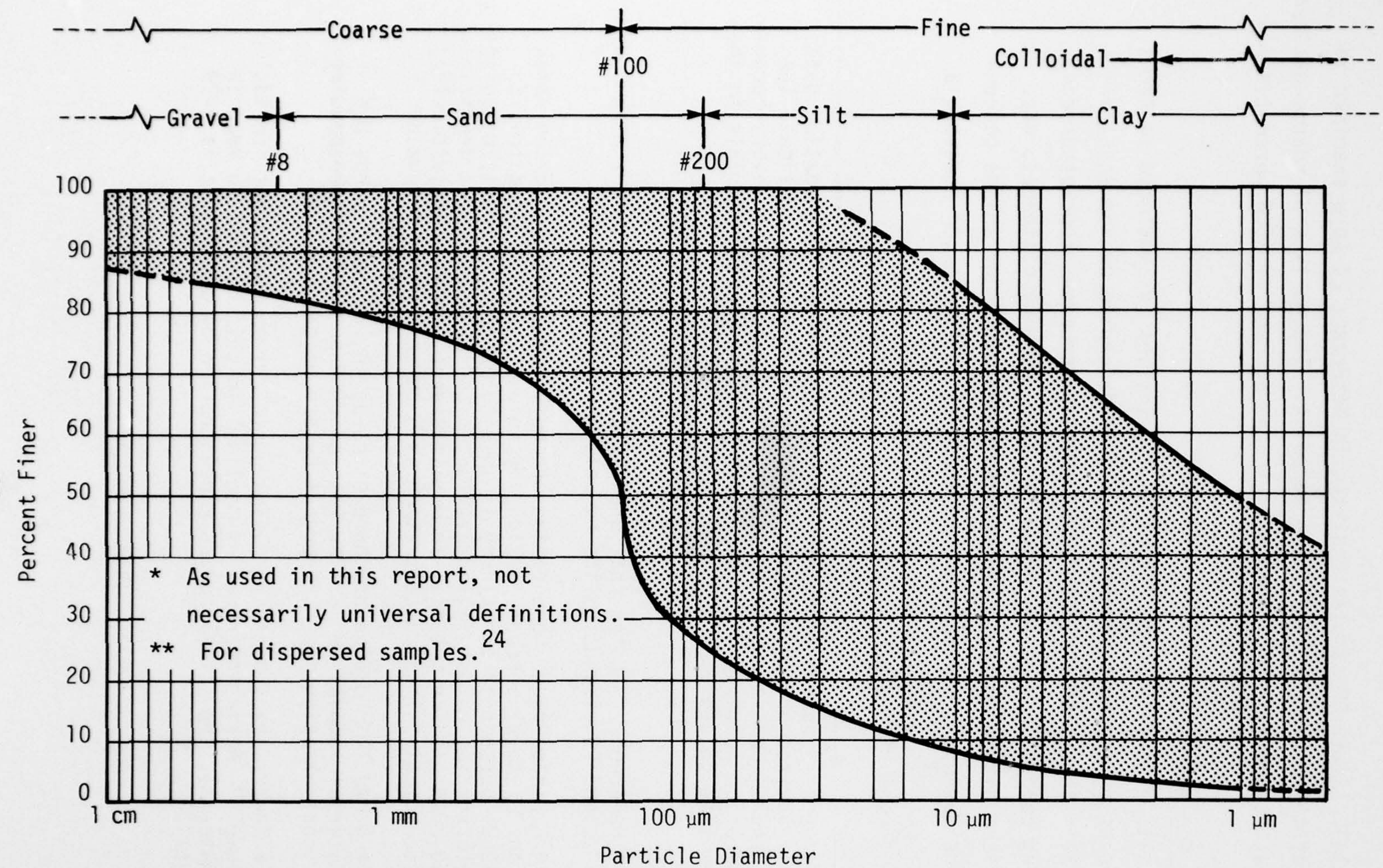

Figure 7. Definitions*; Envelope of Dredged Material Gradation Curves**

143. Sixty DM samples analyzed in Reference 24 were examined in light of the 150-μm coarse/fine breakpoint. The portion of coarse-grained material ranged from 0-64 percent, with an average of 15.6 percent.*

Solids Concentration

144. The solids concentration in slurries (as measured in terms of percent by dry weight) can vary widely depending on the in situ material's characteristics and sedimentation process, type of dredge, dredging conditions (depth, height of face, pumping distance), etc. There is a disagreement on typical and upper limits of solids concentrations during normal maintenance dredging activities;** however, a

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* Reference 24 uses a dispersed analysis to derive its gradation data. This ill-advised procedure (see Paragraph 46) does not invalidate the above conclusions regarding the coarse/fine breakpoint, however, because agglomeration normally does not affect sand and gravel materials in the ≥150-μm size catagory.

** Notes:

- Reference 24 notes that dredges usually pump slurries with between 10 and 20 percent solids by weight.

- A Dixie Dredge Corporation brochure tabulates production rates based on 10 to 21 percent "solids" by volume. Interpreting this to mean 10-21 percent of the slurry is in situ material (comprising solids and interstitial voids filled with water and having typical densities of 1300-2000 g/l for material from maintenance dredging activities[28]), then the actual solids concentration is 5-28 percent by dry weight.

- A Mud Cat dredge brochure cites up to 120 cubic yards per hour material removal and a flow rate of 2000 gpm. The corresponding solids concentration is 9-27 percent by dry weight.

- The St. Paul District claims up to 20 to 30 percent "solids" by volume.[10] Again interpreting "solids" in this context to mean in situ material, the actual solids concentration by dry weight is 9-29 percent.

range of 5-30 percent probably covers the majority of cases. Figure 8 indicates the delivery rate of solids corresponding to various slurry flow rates and solids concentrations.

145. The disposal/processing operations in this report refer to two types of dredges--primary and secondary. A primary dredge (mechanical or hydraulic) operates at the dredging location to remove in situ material. A secondary dredge is a small hydraulic dredge used to bring DM on site or to rehandle DM during processing. Examples in this report assume that slurries from primary hydraulic dredges and secondary dredges have solids concentrations of 10 and 20 percent by dry weight respectively.*

Dredge Flow Rates

146. A representative range of hydraulic dredge flow rates (used to size settling basins, etc.) was selected from the discharge values shown in Table 6.

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* Notes:

- An exception to these percentages is a secondary dredge serving a holding basin. Here, the solids concentration of the slurry entering the holding basin should be used (assuming water is neither added to nor lost from the holding basin).

- The secondary dredge achieves higher solids concentrations than a primary dredge because it handles freshly settled sediments which are easier to put into suspension and draw into the suction line. Also, the Mud Cat dredge (representative of a practical and economical secondary dredge) has a transversely-mounted auger cutterhead which feeds sediment to the suction line in a more concentrated form than is generally achieved with a normal cutterhead, dust pan, or draghead dredge.

Notes: SDR = 0.25 Q/(100/C - 1 + 1/SG)
C = 100/[Q/(4 SDR) - 1/SG + 1]
Q = 4 SDR (100/C + 1/SG -1)
Plots drawn for solids SG = 2.65
Can multiply both abscissa and ordinate by 10 to consider larger Q or SDR.

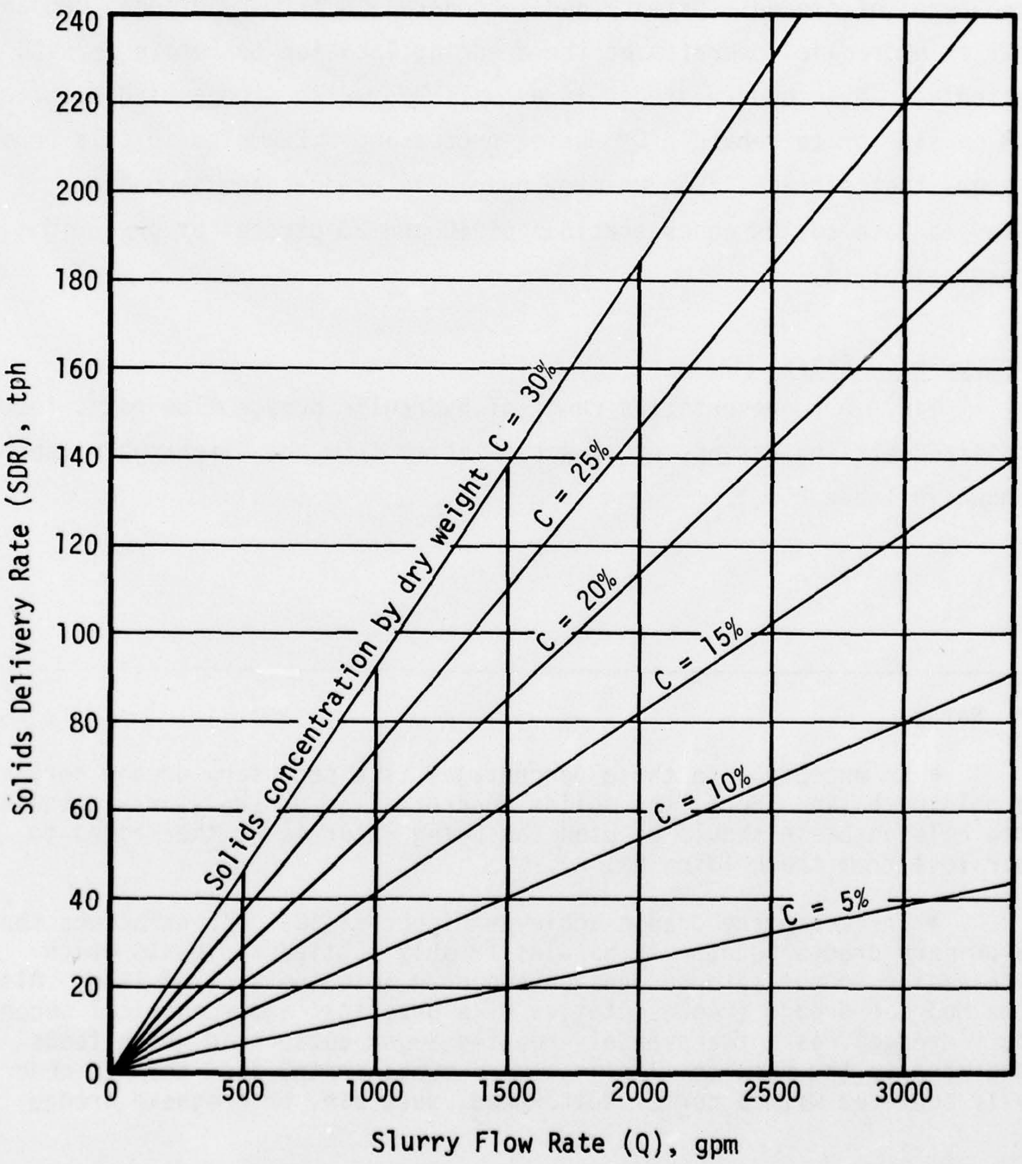


Figure 8. Delivery Rate of Solids at Various Slurry Flow Rates and Solids Concentrations

Table 6

Dredge Slurry Flow Rates

Discharge Line I.D., inches	Velocity,* fps	Flow Rate cfs	Flow Rate gpm
8	12.0	4.2	1,880
10	13.4	7.3	3,280
12	14.8	11.6	5,180
14	15.9	17.0	7,620
16	17.0	23.7	10,640
18	18.0	31.8	14,280
20	19.0	41.4	18,580
24	20.8	65.3	29,300
27	22.0	87.7	39,350
28	22.4	96.0	43,090
30	23.2	114.1	51,200
36	25.5	180.0	80,770

* Velocities were computed from:

$$\text{Velocity} = [\text{Discharge line I.D. (inches)} / 8]^{0.5} \times 12 \text{ fps}$$

where the 12-fps value was adopted for an 8-inch dredge as a safe minimum to prevent settling of even gravel-sized materials.[26]

ALTERNATIVE DISPOSAL SYSTEMS

147. During the studies leading to this report, many conceptually interesting disposal systems were considered; most were eliminated early because of obvious engineering or economic shortcomings. The only systems presented in detail in this report are those which appear capable of performing satisfactorily and which are economically competitive. In many cases, a specific process or piece of equipment has not been used very extensively, if at all, with DM or at the flows and solids concentrations characteristic of DM processing. In these cases, reliable performance and cost figures will require prototype tests.

148. Schematics of viable alternative disposal systems are shown in Table 7 and are contrasted with the conventional disposal site. The systems range in complexity from a simple non-reusable site designed solely to provide an acceptable effluent quality to a reusable site capable of providing ASTM spec materials as well as a high-quality effluent. The reader selects the system or systems best suited to each of the candidate sites which have passed the screening tests of Chapter 4. Figure 9 and its accompanying descriptive pages complement Table 7 by aiding the reader in making logical decisions regarding the DM disposal/processing system. The references in these schematics direct the reader to sections of the report that will assist in selecting specific processes and equipment and in costing the disposal site.

Table 7

Alternative Disposal Systems

TYPE OF DISPOSAL SITE	TYPE OF INFLUENT	SCHEMATIC/FEATURES/LIMITATIONS/REFERENCES
CASE 1: NON-REUSABLE--CONVENTIONAL	SLURRY AND NONSLURRY	INCOMING DM → SETTLING BASIN OR CONTAINMENT AREA → EFFLUENT → RECEIVING BODY • Settling basin design established by storage needs or available acreage with little or no consideration of settling processes. • No effluent treatment to remove excess suspended material or pollutants. • DM drains naturally and is not recovered from basin. • This type of facility is not recommended because of obvious environmental shortcomings and rapid consumption of available sites.

Table 7 (continued)

CASE 2: NON-REUSABLE	NONSLURRY	INCOMING DM → $\boxed{\text{CONTAINMENT AREA}}$ → OUTFLOW → $\boxed{\text{POLLUTION TREATMENT}}$ → EFFLUENT → /RECEIVING BODY/

• Number one consideration in site design is effluent quality; number two consideration is extending site life.

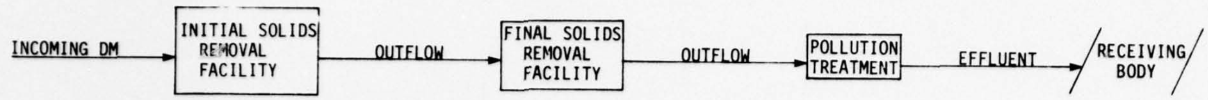
• Solids not recovered from containment area; may use densification techniques (Chapter 7) to enhance dewatering/consolidation to reclaim storage volume or to prepare site for some end use.

• Nonslurry influent simplifies handling, but still might yield some outflow requiring collection (e.g., by underdrain system) and treatment to remove pollutants (Chapter 7).

• This type of disposal site is not addressed in detail in this report because it basically is a simple facility comprising a diked area designed for storage volume and, if required, a standard leachate collection/ treatment system.

Table 7 (continued)

CASE 3: NON-REUSABLE   SLURRY



- Number one consideration in site design is effluent quality; number two consideration is extending site life.
- Solids not recovered; may use densification techniques (Chapter 7) to enhance dewatering/consolidation to restore storage volume or to prepare site for some end use.
- Single-stage solids removal (i.e., no Final Solids Removal (FSR) facility) is possible only in cases where the DM has little colloidal content.*
- A test to determine whether a particular DM is suited for single-stage removal is presented in Chapter 7. Settling basin design is via the procedure recommended for the Initial Solids Removal (ISR) settling basin (Chapter 7).
- Two-stage solids removal (with both ISR and FSR facilities) will be the usual case. The ISR facility removes most of the suspended material and reduces the solids loading on the FSR facility to a level permitting economical flocculation to agglomerate colloidal particles into settleable floc (Chapter 7).
- Outflow is treated to remove pollutants if necessary (Chapter 7).

* The DM gradation data in Reference 24 suggests that fewer than 10 percent of the maintenance dredging locations sampled would lend themselves to single-stage solids removal. (This 10 percent figure might change, however, depending on the stringency of the applicable effluent standard.)

Table 7 (Continued)

CASE 4: REUSABLE--TRANSFER STATION	SLURRY AND NONSLURRY	INCOMING DM → TRANSFER STATION → DM TRANSPORT → DISPOSAL SITE → EFFLUENT → /RECEIVING BODY/

• Primary considerations in site design are effluent quality and extending site life.

• DM is not processed or treated in any way at the transfer station.

• The transfer station may simply be a direct tie-in to a permanent transport facility, e.g., a booster station/pipeline for slurry or a rail car loading system for nonslurry.

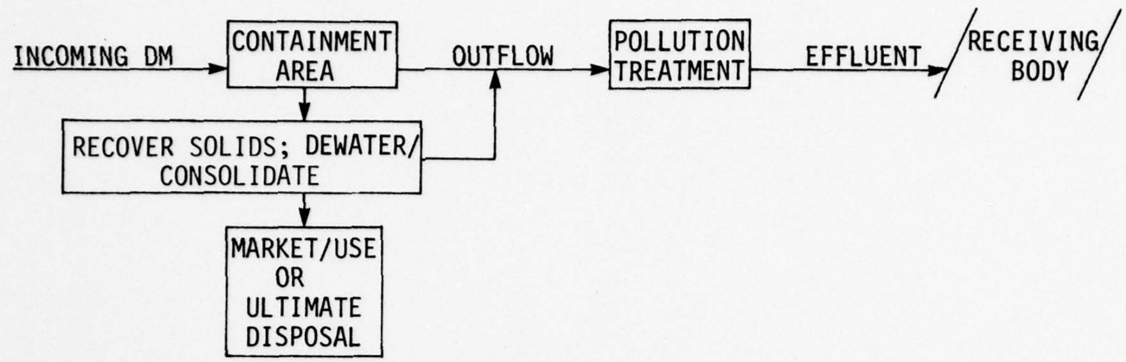
• Alternatively, if a change in transport modes is necessary or if inflow rates exceed transport rates occasionally, the DM may be temporarily stored in a holding basin, then transported to the actual disposal site when convenient.

• This report does not cover transfer station design per se since this type of facility consists primarily of handling/transport systems being addressed in DMRP task 3B01. The methodology in this report applies to the design of the disposal site receiving DM from the transfer station.

Table 7 (continued)

CASE 5:
REUSABLE--
UNCLASSIFIED
SOLIDS OUTPUT

NONSLURRY



• Primary considerations in site design are effluent quality and extending site life.

• This facility yields an unclassified material (i.e., not blended to produce a specific gradation curve) for market/use (e.g., for fill) and/or ultimate disposal. Extremely fine-grained materials, organics, etc., are retained in the "product." This type of operation typifies that being used by some Districts (Philadelphia, for instance) wherein they sell the solids in place for the bidder to pick up and haul away. The natural grading (coarses settle near inlet; fines are carried near outlet) allows bidder to select degree of coarseness desired.

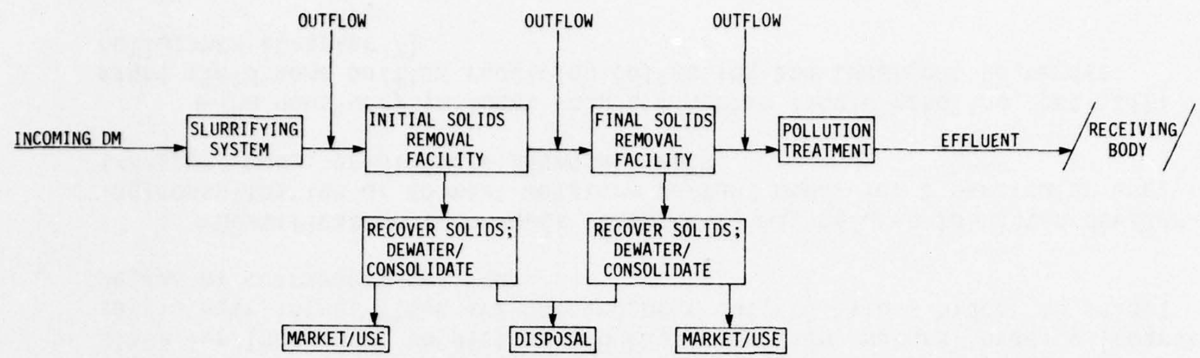
• Densification techniques (Chapter 7) may be used to hasten dewatering/consolidation or to meet moisture content needs for a particular use, transport mode, or ultimate disposal means.

• The nonslurry influent should minimize liquid handling, but still might yield some outflow requiring collection and treatment to remove pollutants (Chapter 7).

Table 7 (continued)

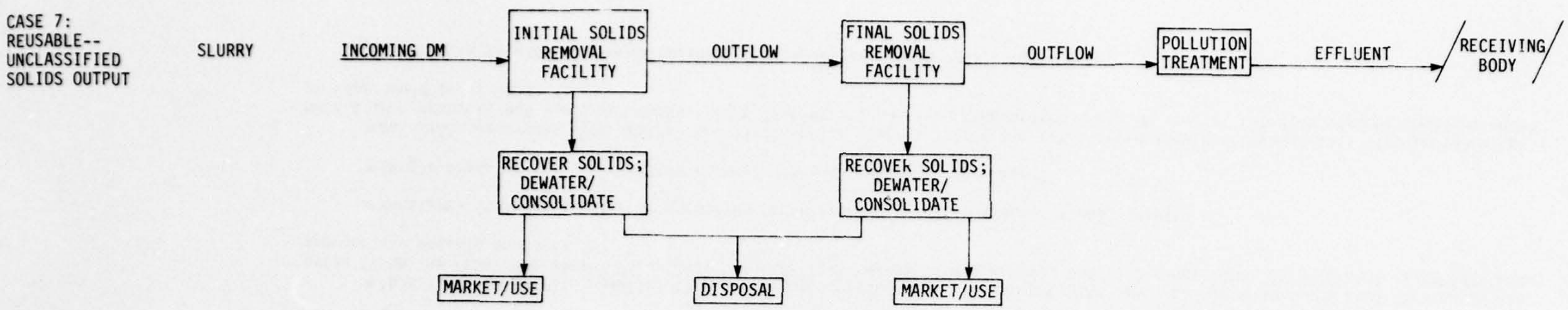
CASE 6:
REUSABLE--
UNCLASSIFIED
SOLIDS OUTPUT

NONSLURRY



- Primary considerations in site design are effluent quality and extending site life.
- This facility yields an unclassified material, but with colloidal and near-colloidal suspended matter separated from the rest. The usual application of this type of facility is when objectionable fine-grained and organic matter must be separated from the DM to make the remainder acceptable for market/use.
- Single-stage or two-stage removal: see discussion under Case 3.
- Densification techniques (Chapter 7) may be used to hasten dewatering/consolidation.
- Outflow is treated to remove pollutants if necessary (Chapter 7).

Table 7 (continued)

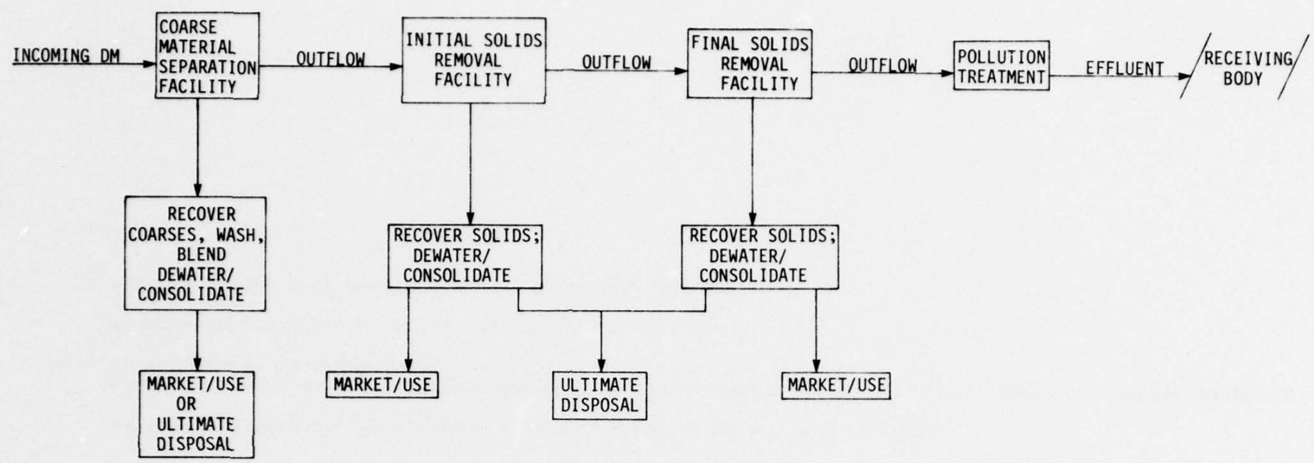


- Primary considerations in site design are effluent quality and extending site life.
- This facility yields an unclassified material (i.e., not blended to produce a specific gradation curve) for market/use (e.g., for fill) and/or ultimate disposal.
- Single-stage or two-stage removal: see discussion under Case 3.
- Outflow is treated to remove pollutants if necessary (Chapter 7).

Table 7 (concluded)

CASE 8: REUSABLE--DESIGN PRODUCT

SLURRY AND NONSLURRY



- Primary considerations in site design are effluent quality and extending site life.

- This facility permits beneficiation of the recovered coarses (Chapter 6) and can yield such products as ASTM Fine Aggregates (from the "coarse-grained" material), landfill (coarse- or fine-grained), and soil conditioner (fine-grained materials with appropriate organic content).

- Nonslurry influent is slurrified during the coarse material separation stage (Chapter 6).

- Single-stage or two-stage solids removal: see discussion under Case 3.

- Materials recovered from initial and final solids removal stages are not blended together because this step would not produce a spec product, but would add costs. If potential user desires a homogeneous mix or special blend, equipment could be added or user could do it himself.

- Outflow is treated to remove pollutants if necessary (Chapter 7).

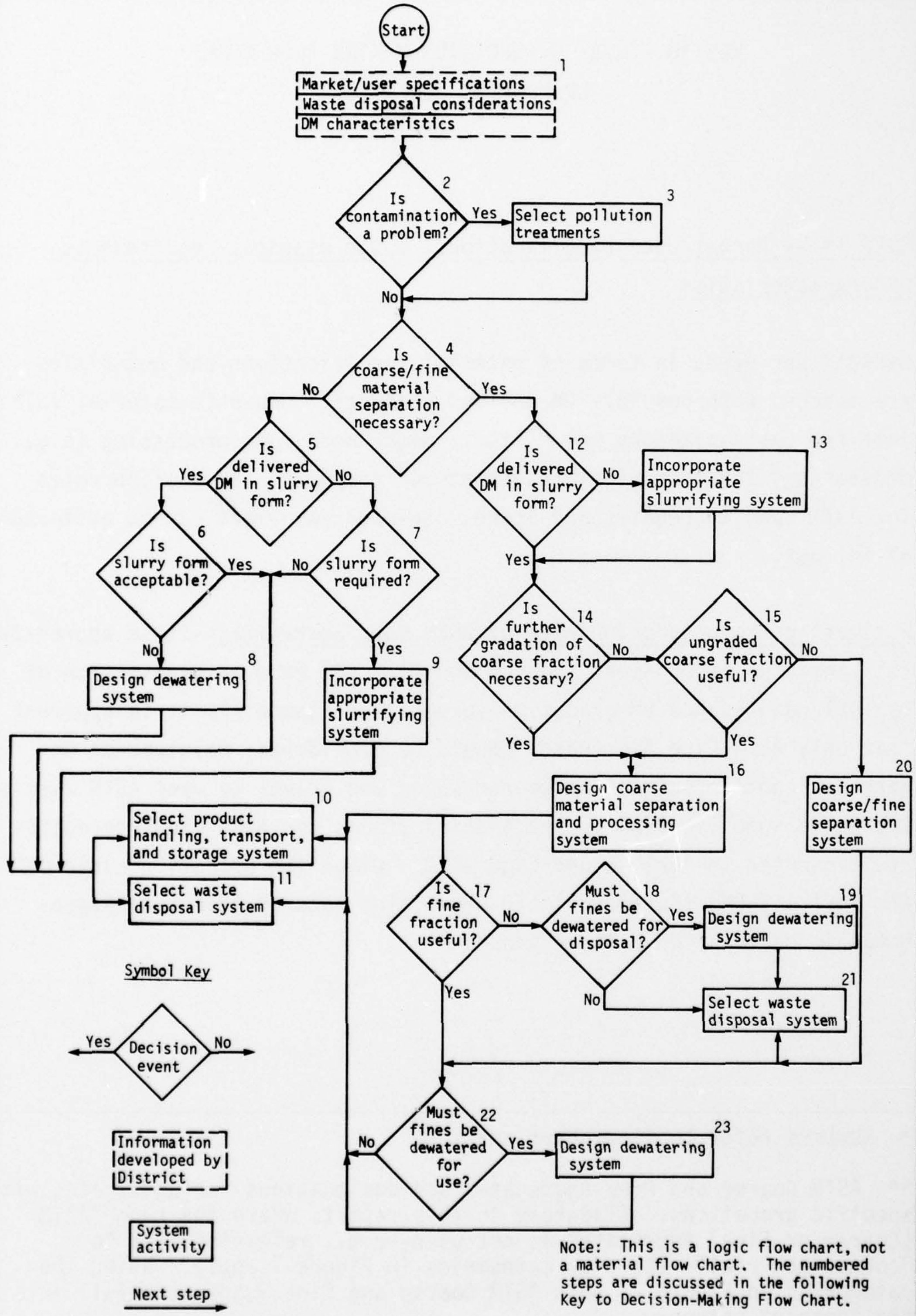


Figure 9. Decision-Making Flow Chart: Dredged Material Process Selection

KEY TO FIGURE 9--DECISION-MAKING FLOW CHART:
DM PROCESS SELECTION

STEP 1* -- Market/user specifications; waste disposal requirements; DM characteristics

Market/user needs in terms of material specifications and quantities are matched with possible DM-derived products. Unusable material falls into the waste category which itself might need some processing (e.g., dewatering) for economical transport and disposal. Production rates for ASTM spec aggregates and other, non-spec materials can be estimated as follows:

Estimating the production rate of ASTM spec aggregates--These aggregates fall into two categories: coarse and fine.** From an examination of typical maintenance DM gradation curves (see Figure 7), it is apparent that only ASTM Fine Aggregates should be considered; maintenance DM does not contain sufficient coarse sands and gravel to meet ASTM Coarse Aggregate specifications. The specifications for ASTM Fine Aggregates are presented in Table 8 and Figure 10. Given the gradation curve of the influent DM, the approximate production rate of ASTM Fine Aggregates is calculated in three steps.

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* Numbers refer to flow chart entries.

** ASTM Coarse and Fine Aggregates are designations for aggregates with specific gradations. Elsewhere in this report, where the term "ASTM [Coarse or Fine] Aggregate" is not used--e.g., referring just to "coarse material"--the size categories in Figure 7 apply. Using the categories in Figure 7, both ASTM Coarse and Fine Aggregates fall into the "coarse" category.

Table 8

Specifications for ASTM Fine Aggregates[26]

Aggregate For Use As	Mesh No.: Mesh Size:	3/8 in. (9.5 mm)	#4 (4.75 mm)	#8 (2.36 mm)	#16 (1.18 mm)	#30 (600 μm)	#50 (300 μm)	#100 (150 μm)	#200 (75 μm)
		Percent Finer Than Designated Square Opening Sieve by Weight							
Concrete Sand or Masonry Grout Aggregate #1		100	95 to 100	80 to 100	50 to 80	25 to 60	10 to 30	2 to 10	...
Masonry Sand or Masonry Grout Aggregate #2									
Natural		100	100	95 to 100	60 to 100	35 to 70	15 to 35	2 to 15	...
Manufactured		100	100	95 to 100	60 to 100	35 to 100	20 to 40	10 to 25	0 to 10
Gypsum Plaster Aggregate		100	100	95 to 100	70 to 95	35 to 70	5 to 35	0 to 10	...

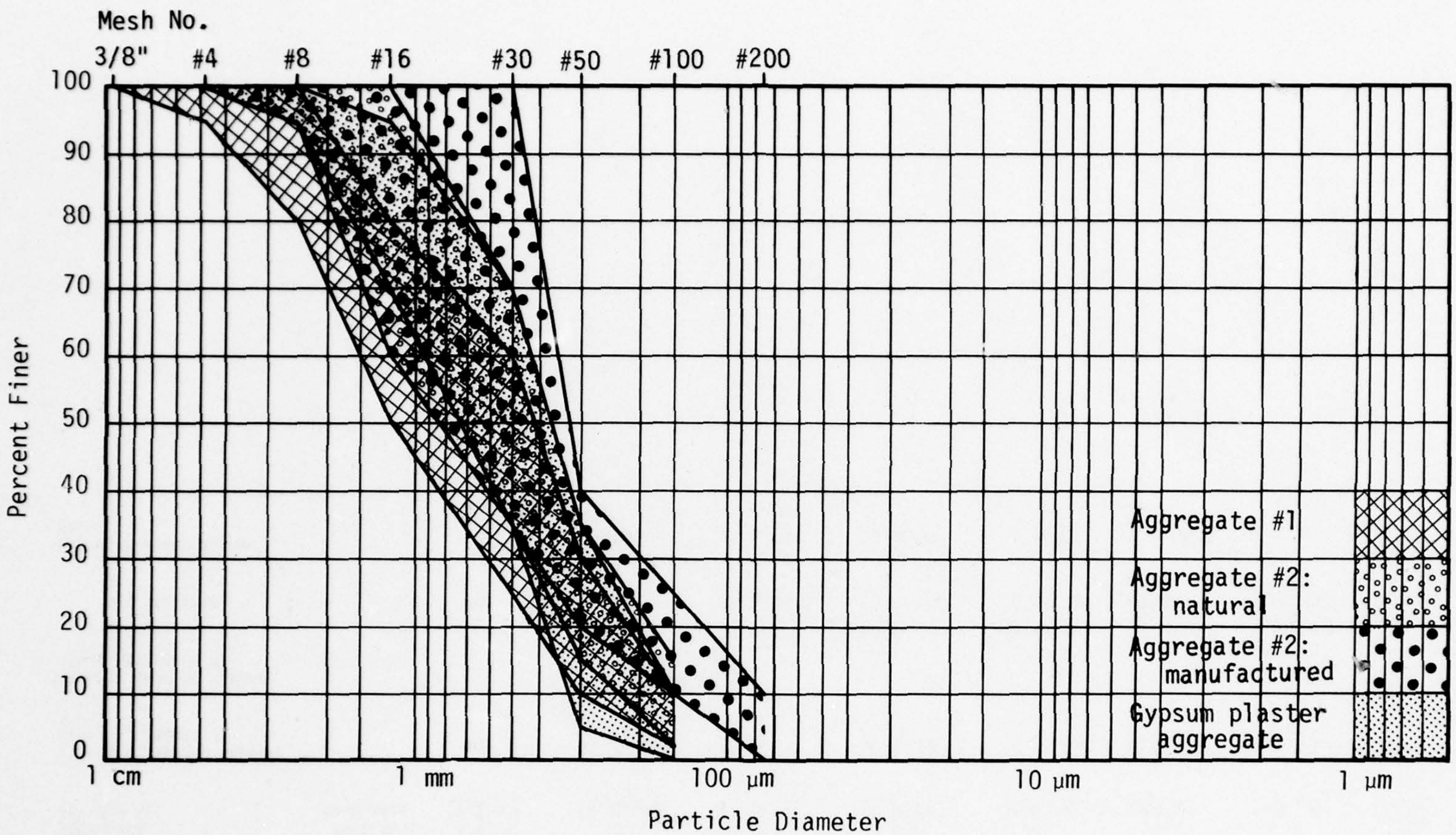

Figure 10. Gradation Envelopes For ASTM Fine Aggregates

• Since the specifications for ASTM Fine Aggregate call for material in the No. 4 to No. 100 range, the fraction of DM falling into this range is read off the gradation curve.*

• 60-80 percent of this fraction can be converted to ASTM Fine Aggregate.**

• The resulting figure is multiplied by the incoming solids rate to obtain the production rate of ASTM Fine Aggregates.

More exacting computations--e.g., trying to pin the 60 to 80 percent figure down better or trying to distinguish between the different ASTM Fine Aggregates--are neither readily done nor deemed warranted in light of the great similarity in composition of these aggregates versus the wide variations in influent DM gradation curves that could occur.

The average annual production of this or any product is estimated as follows:

• Determine the appropriate percentage of all incoming solids (as was done in the first two steps above).

• Compute the in situ solids density (S) from the in situ bulk density (B) using Equation 5:

$$S = SG\ (B - 1000)/(SG - 1) \qquad \text{Equation 5}$$

• Determine the average annual solids production by multiplying the in situ solids density by the projected annual volumetric dredging rate.

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* Note: For production rate predictions, we recommend using the <u>median</u> (or <u>weighted average</u>) gradation curve within the gradation envelope, rather than the envelope's fine-grained boundary (which is recommended for use in designing settling basins).

** The 60 to 80 percent range was established on the basis of computations involving several of the 60 sample gradation curves provided in Reference 24. Note that although the gradation curves in this reference were derived via the unrecommended dispersed analysis, the results are still applicable to ASTM Fine Aggregates because the No. 4 to No. 100 range generally is not affected by dispersing agents.

• Multiply the percentage determined in the first step by the annual solids production determined in the third step.

<u>Example computation of ASTM Fine Aggregate production</u> --

Given:	• Slurry inflow rate (Q)	= 16,000 gpm
	• Solids concentration by weight (C)	= 10%
	• Hypothetical gradation envelope in Figure 11	
	• Projected average annual dredging rate	= 100,000 cy
	• In situ bulk density	= 1600 g/l
	• Solids specific gravity (SG)	= 2.65

Then: Figure 8 shows a solids production rate of about 430 tph. The median gradation curve in Figure 11 shows about 40 percent or 172 tph is in the No. 4 to No. 100 size range. Therefore, 103-138 tph (60-80 percent of 172 tph) of ASTM Fine Aggregate can be produced. The in situ solids density is 2.65 (1600 - 1000)/(2.65 - 1) = 964 g/l. The average annual solids production will be approximately 100,000 cy/yr x 0.4 x 964 g/l x 8.425 x 10^{-4} (t/cy)/(g/l) = 32,000 tpy of which 60-80 percent or 19,000 - 26,000 tpy will be ASTM Fine Aggregate.

<u>Estimating the production rate of non-spec products</u>--Some markets/users will accept non-spec products, i.e., materials with some upper and lower particle size "limits,"* but without specific gradation envelopes such as those for ASTM Fine Aggregates. Production rates for non-spec materials can be estimated via the following process.

• Establish upper and lower particle size limits for the product.

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* The equipment required to handle the large flow rates that are encountered in DM processing generally rely on sedimentation (particle settling) which does not produce a sharp cutoff at a given particle size.

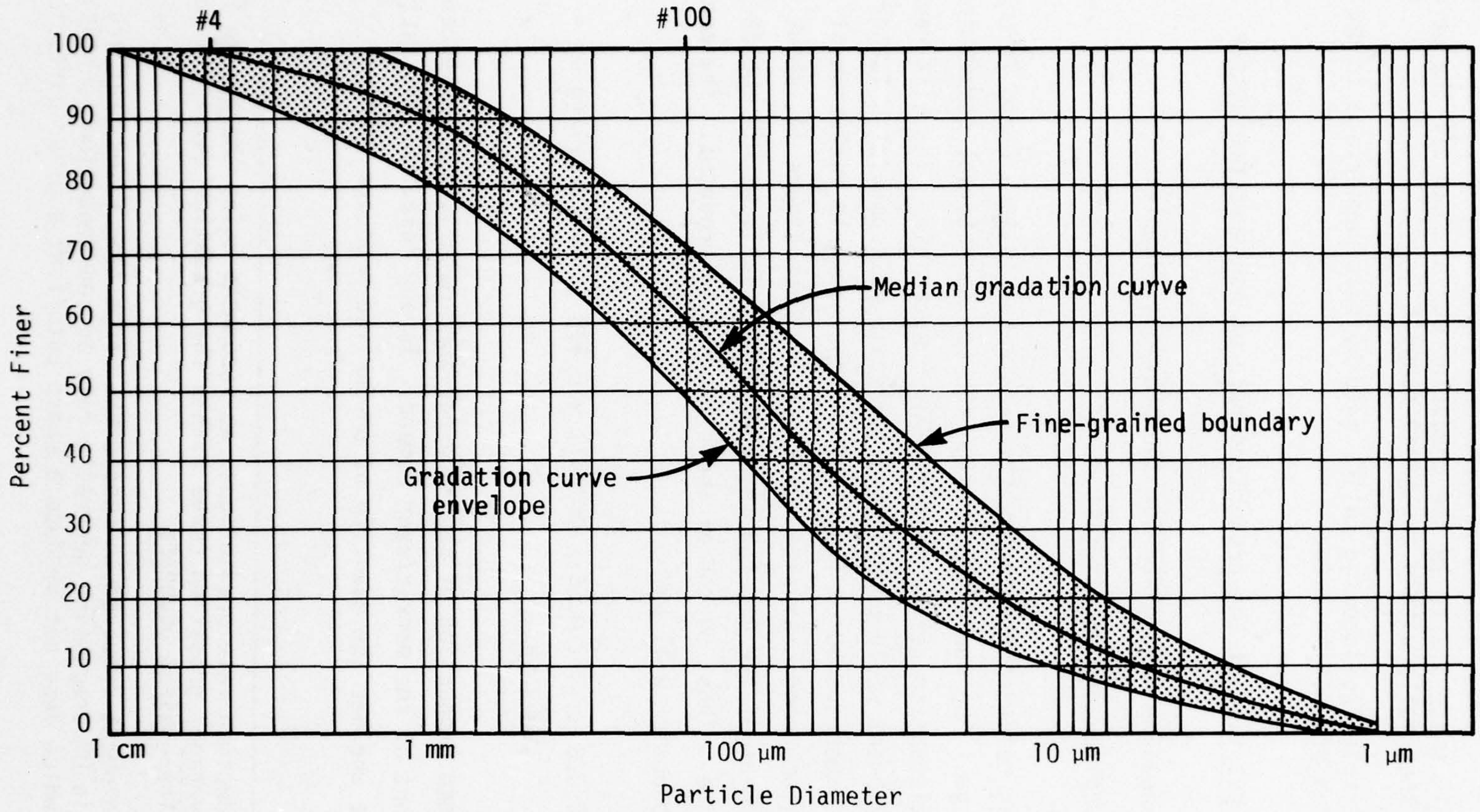

Figure 11. Example Influent Dredged Material Gradation Curve Envelope

• Apply these limits to the gradation curve; read off the percentage of DM that falls within the given range.*

• Multiply the incoming solids rate by this percentage to derive the estimated production rate.

<u>Example computation of the production rate of non-spec products</u>--

Given: • The same data given for the previous example.

• Desired product is silt.

Then: Most references define silt as material in the 10- to 75-μm size range. One would thus design the coarse material separation equipment to retain most** >75-μm materials. The silt removal equipment would be designed to retain most particles larger than perhaps 30 μm (to eliminate the possible inclusion of agglomerated clay-sized particles). From Figure 11, about 16 percent of the 430 tph incoming solids falls within the 30- to 75-μm range. Thus, 69 tph of the silts can be produced. The annual production will be

$$100{,}000\ \text{cy/yr} \times 0.16 \times 964\ \text{g/l} \times 8.425 \times 10^{-4} (\text{t/cy})/(\text{g/l}) = 13{,}000\ \text{tpy}$$

The estimated production of spec and non-spec materials might exceed or fall short of the market/user demand. In any case, the District must decide whether the quantity of DM-derived products that are

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* For production rate predictions, we recommend using the <u>median</u> (or <u>weighted average</u>) gradation curve within the gradation envelope, rather than the fine-grained boundary.

** The equipment required to handle the large flow rates that are encountered in DM processing generally rely on sedimentation (particle settling) which does not produce a sharp cutoff at a given particle size.

marketable/usable warrants the costs for extra processing and egress/ off-site transport. Consider the above example. The annual dredging rate was

$$100{,}000 \text{ cy/yr} \times 964 \text{ g/l} \times 8.425 \times 10^{-4} (\text{t/cy})/(\text{g/l}) = 81{,}000 \text{ tpy}$$

from which an ASTM Fine Aggregate production of 19,000-26,000 tpy and a silt production of 13,000 tpy could be derived. If all the ASTM Fine Aggregate and all the silt were marketable/usable, the remaining waste would amount to 42,000-49,000 tpy. This 40 to 48 percent reduction in waste disposal needs might well be cause for choosing to invest in a complex processing facility. However, if only a portion of the ASTM Fine Aggregate and none of the silt was marketable/usable, this decision might not be self-evident. The District might have to proceed to cost out the processing and waste disposal sites and transport to make an informed decision.

STEP 2 -- Is contamination a problem?

Is the DM chemically or organically contaminated to the extent that processing, marketing/use, or waste disposal requires special treatments? This question applies to both liquid effluent and solids. When addressing solids, this question normally applies to ungraded material or the fine fraction (if coarse/fine separation is to be used) because contaminants generally associate with fine materials.[29] When addressing effluent, this question applies to contamination other than suspended solids (which are removed to meet applicable standards regardless of other contaminants).

STEP 3 -- Select pollution treatments

If the response to STEP 2 is "yes," the reader must select specific treatments and their point of application. Solids treatments might be applied to the influent DM or a particular solids fraction after separation; or steps might be taken at the ultimate destination (such as installing a leachate collection and treatment system) to prevent adverse effects from pollutants. For the effluent, the treatments might be applied to the influent DM, to the final effluent, or at some interim outflow stage. In light of the fact that the DMRP has not produced specific pollution treatment recommendations, we suggest that the applicability of standard treatment methods be examined as required.

STEP 4 -- Is coarse/fine material separation necessary?

The answer depends on the results of the market/user survey and the District's judgment regarding the relative value of investing in the extra processing equipment to satisfy the demand for a graded product.

STEP 5 -- Is delivered DM in slurry form?

This question refers to the DM condition as delivered by the dredge-initial transport plant. If a pipeline is the transport mode, the DM is in a slurry form. If a barge is the transport mode, the DM is in a nonslurry state.

STEP 6 -- Is slurry form acceptable?

This question (and STEP 7) apply to ungraded DM which might be totally, partially, or not marketable/usable (and, conversely, not, partially, or totally destined for waste disposal). Thus, both product and waste

disposal needs must be considered. If a slurry is acceptable for waste disposal, but not acceptable for market/use, the District must weigh the advantages of marketing/using some portion of the DM against the extra costs for incorporating the necessary dewatering system in the plans.

If the response to STEP 5 is "yes," and if a slurry is acceptable for both product and waste, the reader proceeds directly to STEPS 10 and 11. If either product or waste need be in nonslurry form, the reader proceeds to STEP 8 before STEPS 10 and 11.

STEP 7 -- Is slurry form required?

The same types of considerations as in STEP 6 apply. If the response to STEP 5 is "no," the delivered DM is in a dewatered form. If this form is acceptable for both product and waste portions, the reader proceeds directly to STEPS 10 and 11. If a slurry form is required for either, then the reader proceeds to STEP 9 before STEPS 10 and 11.

STEP 8 -- Design dewatering system

See Chapter 7 to design the appropriate solids removal/dewatering system.

STEP 9 -- Incorporate appropriate slurrifying system

The system for bringing the delivered DM into the disposal site could be selected so as to provide a slurry influent (see Chapter 7) or, if the incoming DM will be in a nonslurry state, a simple slush box with integral pump-out system could be added.

STEP 10 -- Select product handling, transport, and storage system

The useful portion of the ungraded DM must be provided with an appropriate handling/transport/storage system to use it or make it available to markets/users. The District should refer to DMRP task 3B01, "A Study of Dredged Material Transport Systems for Inland Disposal and/or Productive Use Concepts."

STEP 11 -- Select waste disposal system

The useless portion of the ungraded DM must be provided with a waste disposal system. This system might involve handling/transport equipment being addressed in DMRP task 3B01. If the waste is in a nonslurry form, a simple solid waste disposal system is needed (with leachate control and treatment if necessary). If the waste is in a slurry form, the reader should see Chapter 7 for discussions of solids removal methods that would be included in the waste disposal site plans.

STEP 12 -- Is delivered DM in slurry form?

Same as STEP 5.

STEP 13 -- Incorporate appropriate slurrifying system

Coarse/fine material separation systems require a slurry form; therefore, if the response to STEP 12 is "no," a slurrifying system must be included. Equipment bringing the DM into the disposal site can be selected so as to provide a slurry influent or, if a nonslurry input is necessary or desirable, wash water can be added during the separation stage to produce a slurry. See Chapter 6.

STEP 14 -- Is further gradation of coarse fraction necessary?

It was determined in STEP 4 that separation of coarse and fine materials is necessary. It must now be decided if the market/user situation makes it advantageous to further process the coarse fraction--separating it into different size ranges and reblending in specific proportions (e.g., to produce an ASTM Fine Aggregate).

STEP 15 -- Is ungraded coarse fraction useful?

If the response to STEP 14 is "no," the reader must decide which ungraded fraction, coarse or fine (or both) is useful. STEP 15 establishes the usefulness of the coarse fraction.

STEP 16 -- Design appropriate coarse material separation and processing system

If the response to STEP 14 is "yes," the reader proceeds to Chapter 6 to design a coarse material separation and processing (CMSP) facility capable of producing a graded coarse product.

If the response to STEP 15 is "yes," the reader proceeds to Chapter 6 to design a CMSP facility to separate and process (e.g., dewater) the coarse fraction in accordance with market/user needs.

In both of the above cases, the reader then proceeds to STEP 10 to select a handling/transport/storage system for the resulting product and to STEP 11 to select a waste disposal system for excess, unusable coarse material. (Note that the coarse fraction is produced in a stackable form, not a slurry form, although the coarse product can be reslurrified via a slush box with integral pump-out system if this is desirable, e.g., for pipeline transport.) The reader also proceeds to STEP 17 to determine the usefulness of the fine fraction.

STEP 17 -- Is the fine fraction useful?

At this point, the coarse fraction has been declared useful. This step establishes whether the fine fraction also is marketable/usable.

STEP 18 -- Must fines be dewatered for disposal?

If the response to STEP 17 is "no," then the entire fine fraction must be disposed of as waste. This step establishes the acceptable physical state of the material for disposal.

STEP 19 -- Design dewatering system

If the response to STEP 18 is "yes," the fine fraction (which is in a slurry form at this point) must be dewatered. The reader should refer to Chapter 7 for the appropriate design procedures. Then the reader should proceed to STEP 21.

STEP 20 -- Design appropriate coarse/fine separation system

If the response to STEP 15 is "no," it can be concluded that there must be a market/use for the fine fraction or the response to STEP 4 would have been "no." Therefore, the reader refers to Chapter 6 to design the coarse/fine separation system. The reader then proceeds to STEPS 21 and 22.

STEP 21 -- Select waste disposal system

Regardless of the response to STEP 18, the reader must eventually select a waste disposal system for the unwanted fine fraction. This

system could be considered in conjunction with the waste disposal system selected for the excess coarse materials. If the incoming fines are in dewatered form, a simple solid waste disposal system is needed (with leachate control and treatment if necessary). If the incoming waste is still in slurry form, the reader can refer to Chapter 7 for solids removal techniques that would be included in the waste disposal site plans.

After STEP 20, the reader has an unwanted coarse fraction to dispose of as waste. This coarse fraction could be transported to the waste disposal site in either a slurry or nonslurry form as needed. If these coarses are separated via a primary basin (see Chapter 6), recovery by small secondary hydraulic dredge or mechanical means would provide a slurry and nonslurry, respectively. If they are separated in some other fashion whereby they are in stackable form, they could be reslurrified if desired using a slush box with an integral pump-out system. If the coarses are delivered to the waste disposal site in a nonslurry form, standard solid waste techniques apply. If delivery is in a slurry form, a small settling basin would provide adequate solids removal.

STEP 22 -- Must fines be dewatered for use?

Market/user needs will dictate the response to this question. If "no," the reader proceeds to STEP 10 to select the appropriate handling/transport/storage system for the useful portion of the fines fractions and to STEP 11 to select the appropriate waste disposal system for any excess, unwanted fines.

If "yes," the reader proceeds to STEP 23.

STEP 23 -- Design dewatering system

If the response to STEP 22 is "yes," the reader should refer to Chapter 7 for appropriate design procedures. The reader then proceeds to STEP 10 to select the handling/transport/storage system for the useful portion of the fines fraction and to STEP 11 to select the waste disposal system for any excess, unwanted fines.

CHAPTER 6

PHASE III

COARSE MATERIAL SEPARATION AND PROCESSING

OVERVIEW

149. This chapter addresses alternative coarse material separation and processing (CMSP) facilities. Clearly, coarse material separation applies specifically to <u>reusable</u>, not non-reusable sites. The only reason for providing coarse/fine separation is because either the coarse or fine fraction or both are in demand for some market/use. A reusable site need not have a coarse/fine separation stage; there will be situations where:

- A market/use for unseparated coarse and fine materials exists (e.g., landfill).
- No market/use for any DM-derived product exists and all the DM must be disposed of as waste.

In these cases, a reusable facility yielding unclassified solids will suffice and:

- If the incoming DM is in slurry form, then the District can proceed to Chapter 7 for solids removal systems.
- If the incoming DM is in nonslurry form, then the District can design a simple facility comprising a containment basin sized to handle the DM volume which accumulates between scheduled off-site transport loads and, if necessary, systems for additional dewatering/consolidation and leachate collection/treatment. Many of the components of this type of facility can be extracted from this report, but the overall facility is not addressed per se because of its basic simplicity.

ALTERNATIVE SYSTEMS AND COMPONENTS

150. The desired coarse material product determines the type of processing needed. In turn, the type of processing, in conjunction with the type of dredge-initial transport system, influences the means of getting the DM on site. Studies of numerous coarse material processing systems produced ten which provide a variety of useful products at a reasonable cost. Table 9 indicates which system to select to yield the desired product. Figure 12 summarizes the major components of these systems. Figures 13-22 show major components, slurry flow, and solids output for each of the ten systems. These components are described below; capacities, production rates, and capital and operating costs are presented in the preliminary costing discussion beginning with Paragraph 201.

Grizzly

151, Coarse screening, via equipment such as grizzlies, can handle high hydraulic and solids loadings, but does not greatly reduce suspended solids. Therefore, coarse screening is used as a pretreatment where subsequent processing (e.g., by clarifiers) will assure production of the desired effluent. A grizzly (scalping pump box) consists of a steeply inclined screen with parallel bars for interception of oversize material and gravity removal via a chute to a refuse pile for subsequent disposal (see Figure 23).

Vibrating Screen

152. Most separating screens used in industrial processes are subjected to some form of rotary or reciprocating motion in order to disturb the solid material, thereby permitting all the material sooner or later to come into contact with the screen medium. The agitation also helps to break agglomerations of small particles and to detach small particles from larger ones to which they may be adhering, thus

Table 9

Coarse Material Product/Process Selection

Coarse Material Product	1	2	3	4	5	6	7	8	9	10
					Alternative System					
≥3 inch	X	X	X	X	X	X	X	X	X	X
≥No. 8 mesh to <3 inch	X^{ε}	X	X	X	X	X		X	$X^{*,\varepsilon}$	X^{*}
>150 μm§ to <No. 8 mesh										
Classified coarses (washed)			$X^{\dagger}$					$X^{\dagger}$		
Unclassified coarses										
Washed		X	$X^{\dagger}$	X	X		X^{θ}	$X^{\dagger}$		X
Unwashed						X^{ϕ}				

Note: Table read horizontally shows process alternatives yielding coarse product shown. Table read vertically shows various products produced by a given process alternative. See Figures 12-22 for makeup of each alternative processing system.

* Hydrasieves remove down to 0.06 inches (= 1.524 mm) compared to vibrating screens which remove down to No. 8 mesh (= 2.36 mm).

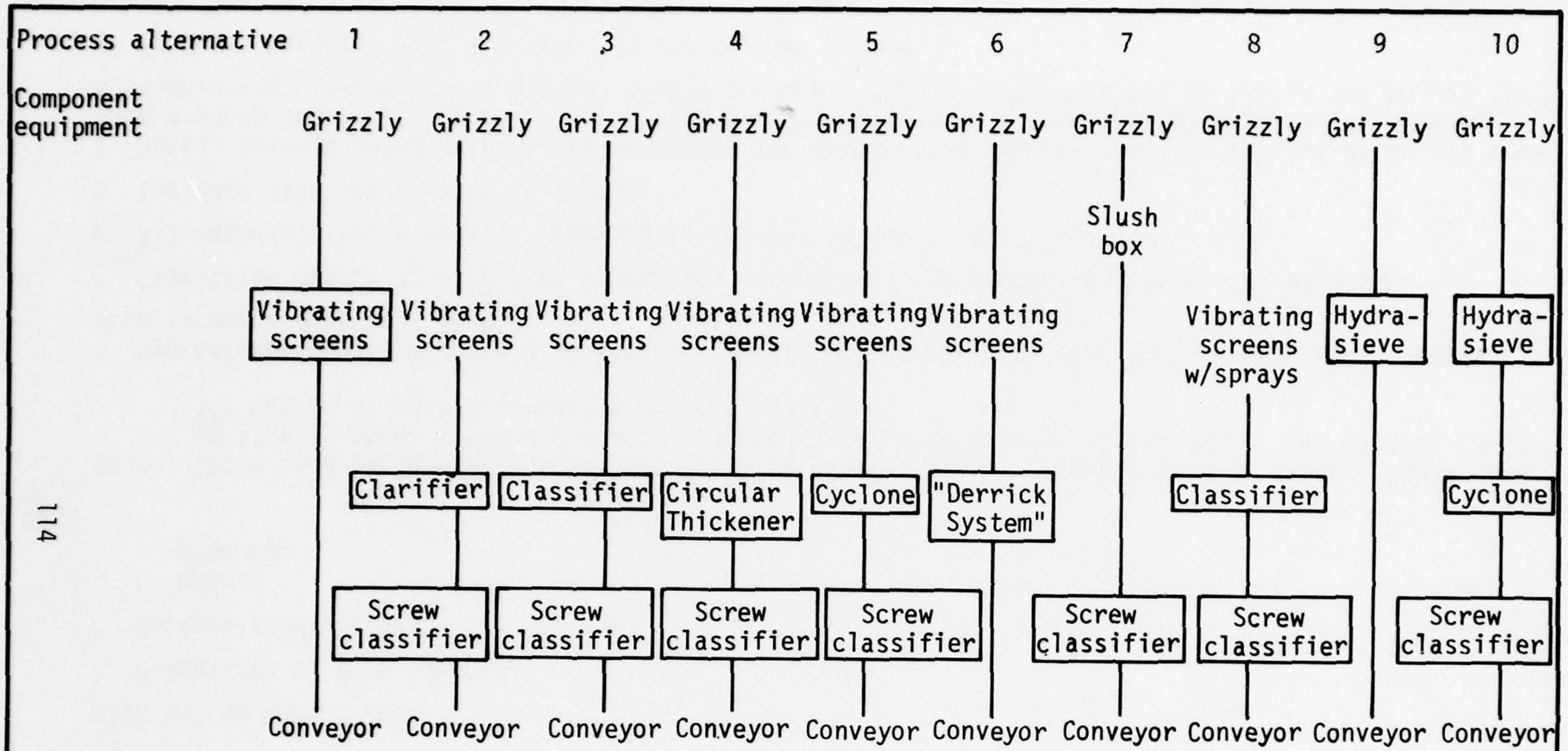
† Classified output is ASTM Fine Aggregate; unclassified by-product may be useful or waste.

ε All material <No. 8 mesh is bypassed to Initial Solids Removal facility.

θ Includes material <3 inch to 150 μm.

§ Note: Systems using natural sedimentation for coarse/fine separation (Nos. 2,3,4,7,8) do not produce a sharp cutoff at 150 μm. Some finer material is retained; some coarser material is bypassed. Systems using cyclones (Nos. 5,6,10) should produce a sharper cutoff at 150 μm (75 μm for No. 6).[30,31]

ϕ Produces material >No. 200 mesh (75 μm) to <No. 8 mesh.



Note: Equipment shown in boxes discharges slurry containing finer-grained materials to the initial solids removal basin.

Figure 12. Alternative Coarse Material Separation and Processing Systems

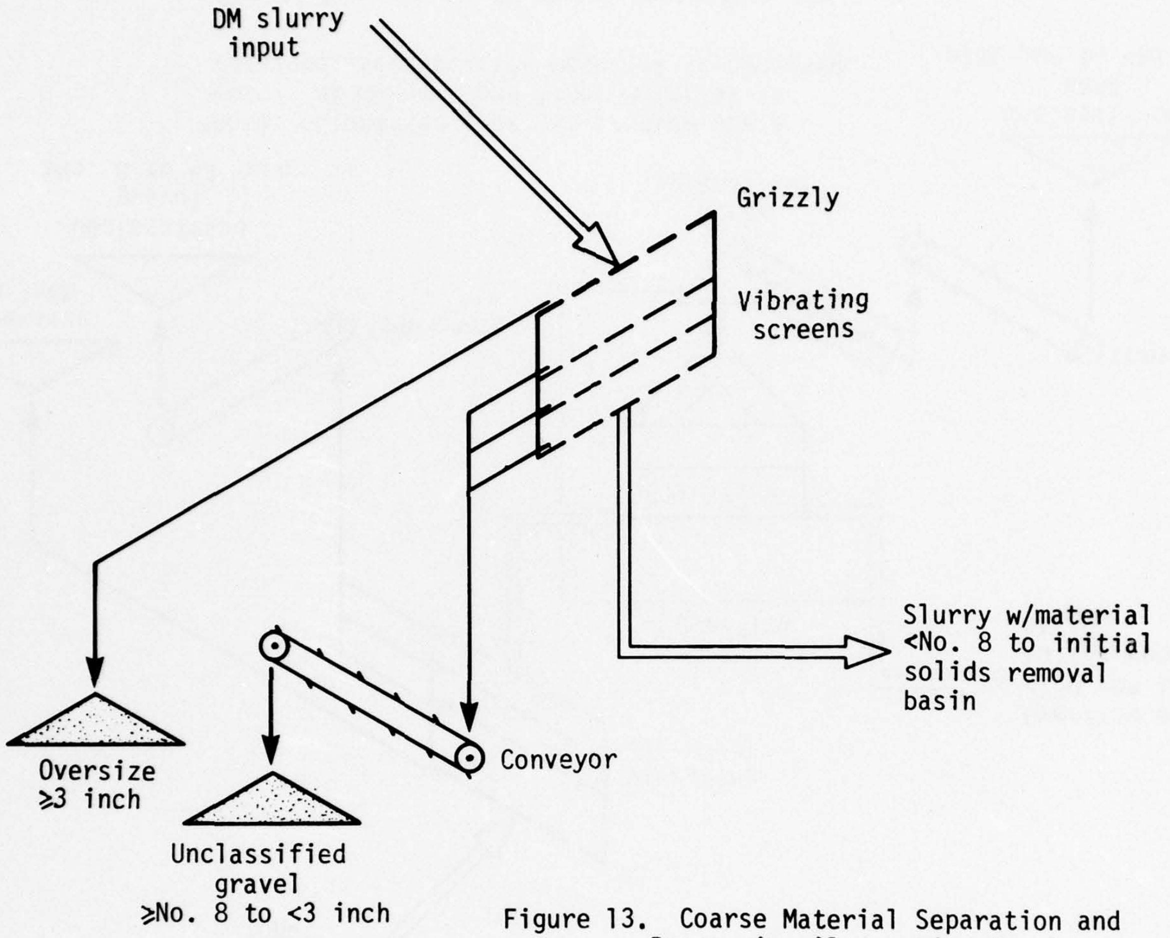
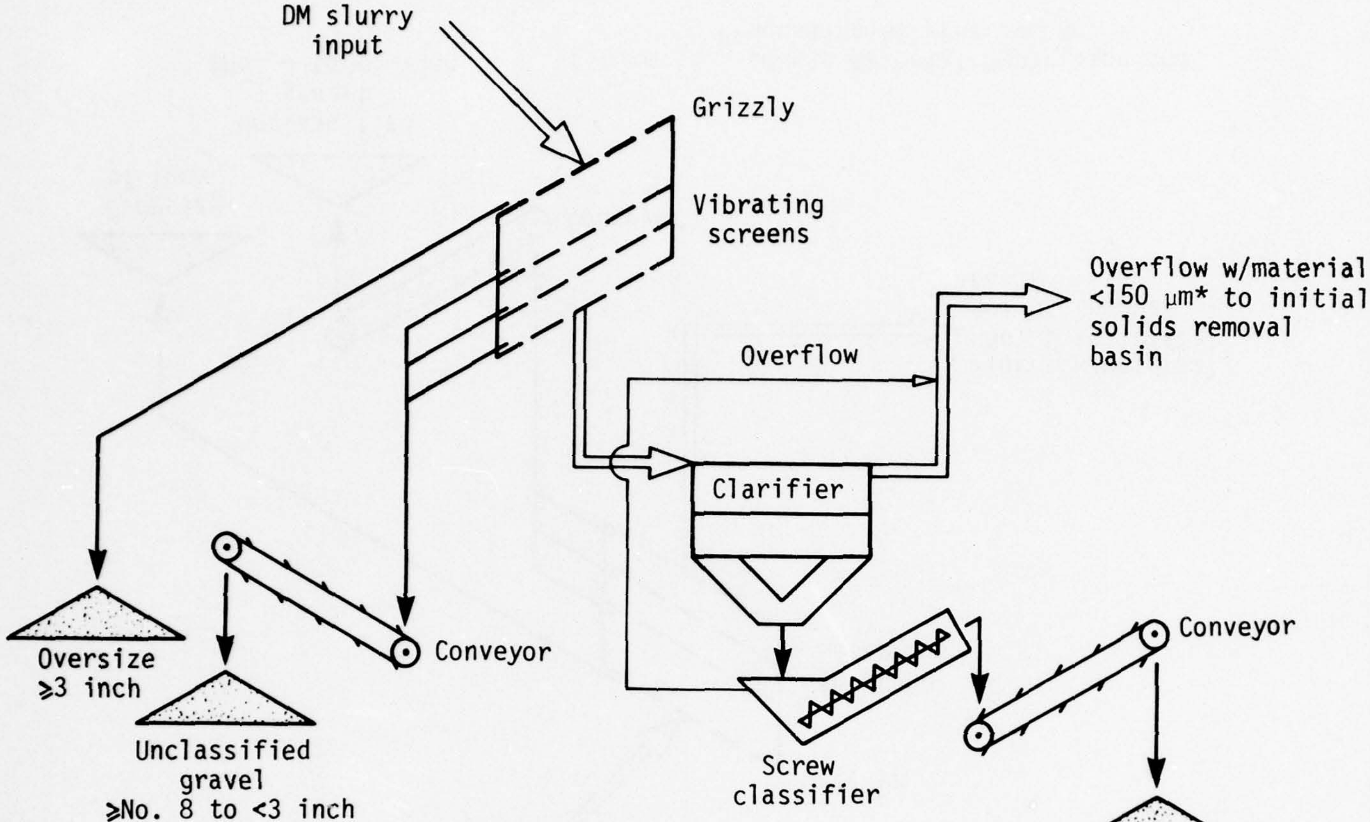
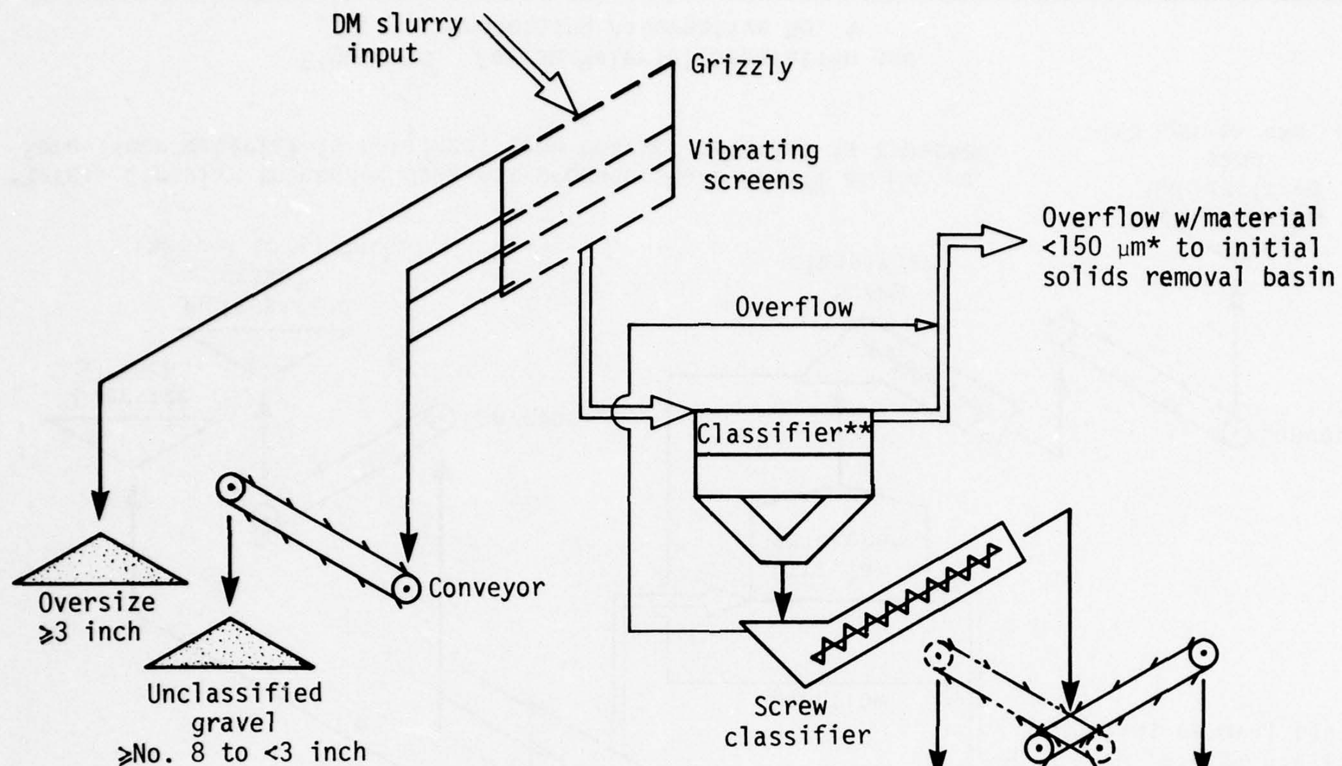


Figure 13. Coarse Material Separation and Processing Alternative No. 1



*Note: Clarifier does not produce sharp cutoff at 150 μm. Some finer material is retained; some coarser material is bypassed.

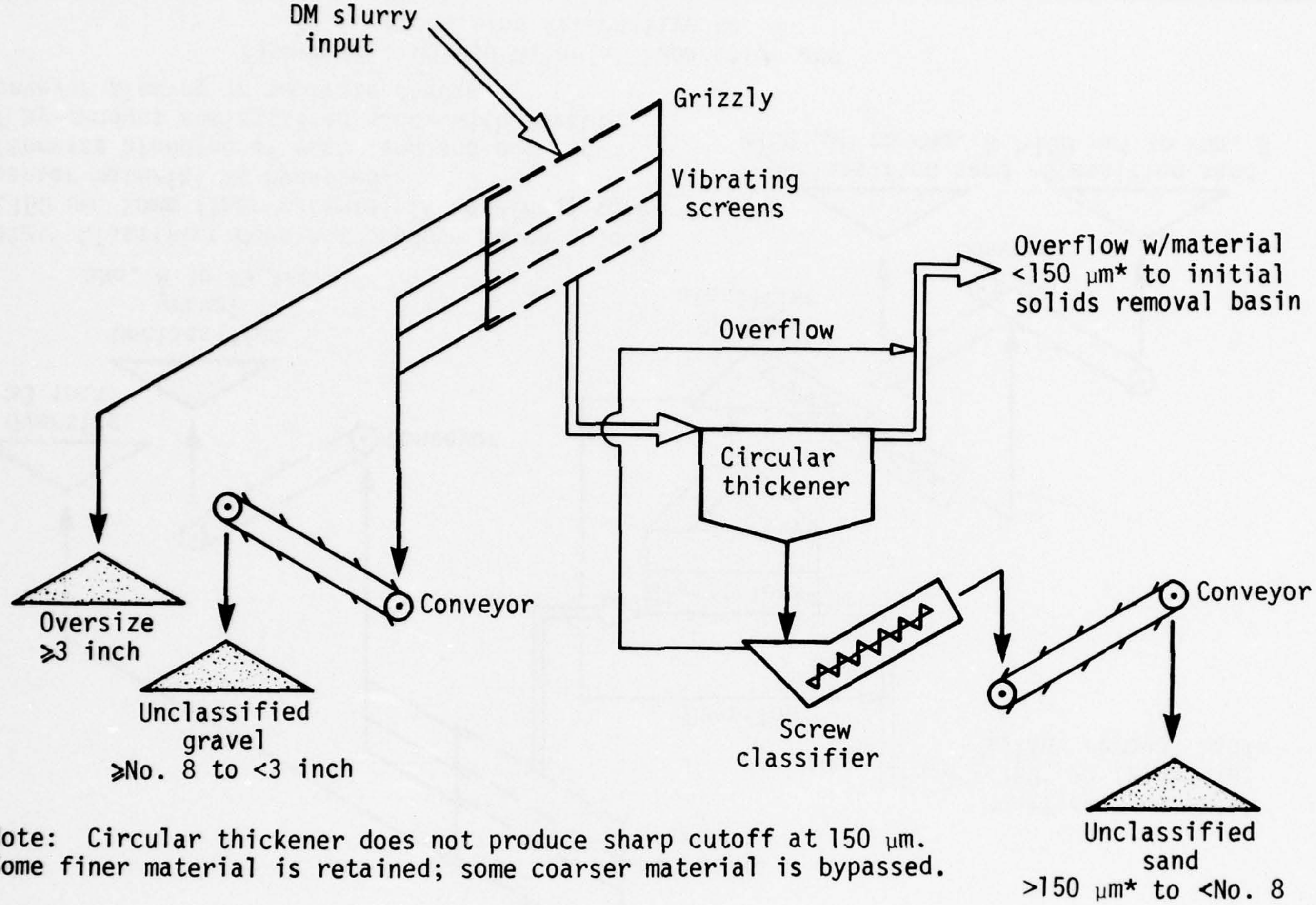
Figure 14. Coarse Material Separation and Processing Alternative No. 2



*Note: Classifier does not produce sharp cutoff at 150 μm. Some finer material is retained; some coarser material is bypassed.

**Alternate blending of spec sand and dumping of by-product unclassified sands with movable conveyor placing in separate stacks.

Figure 15. Coarse Material Separation and Processing Alternative No. 3



*Note: Circular thickener does not produce sharp cutoff at 150 μm. Some finer material is retained; some coarser material is bypassed.

Figure 16. Coarse Material Separation and Processing Alternative No. 4

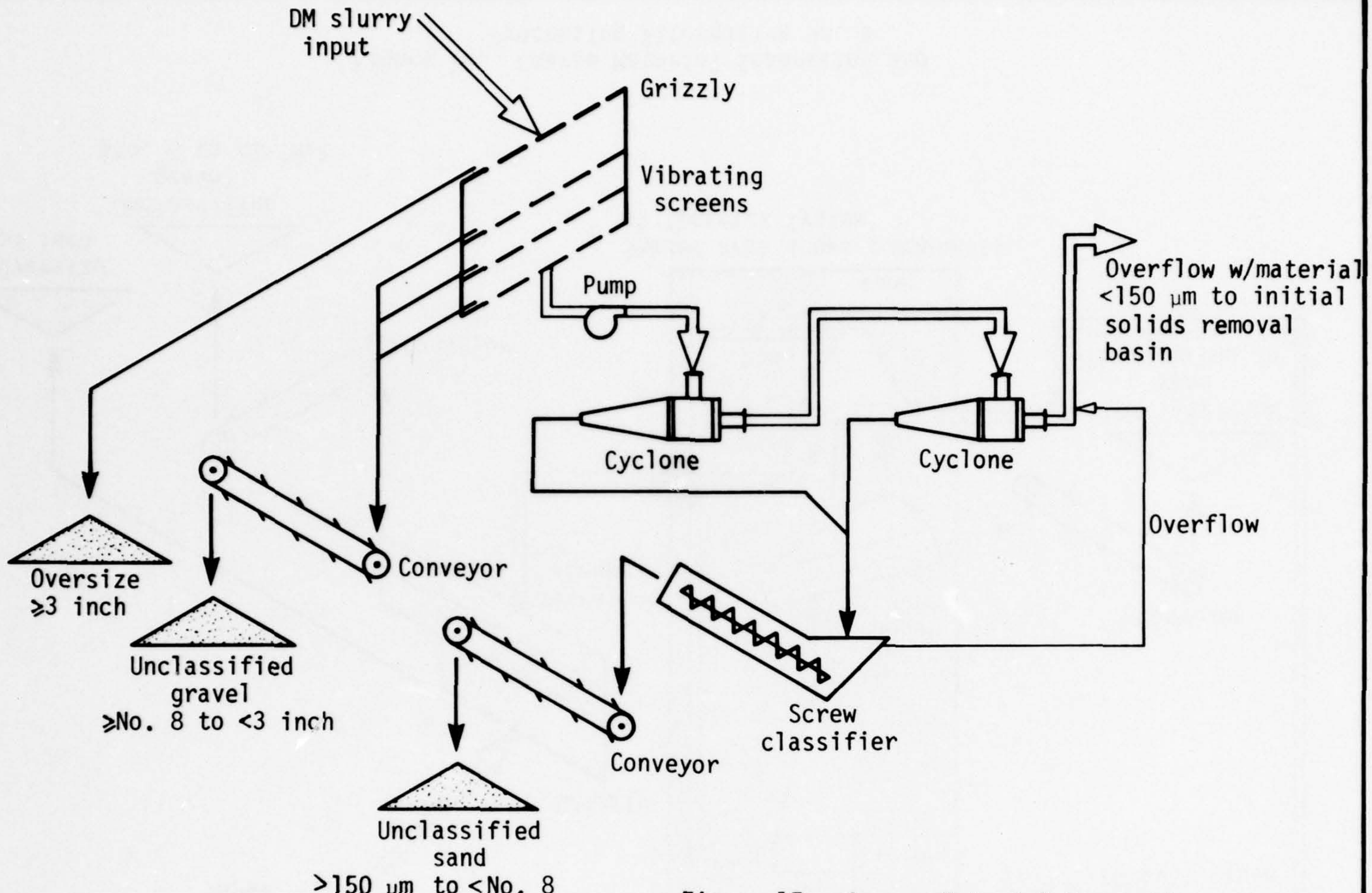


Figure 17. Coarse Material Separation and Processing Alternative No. 5

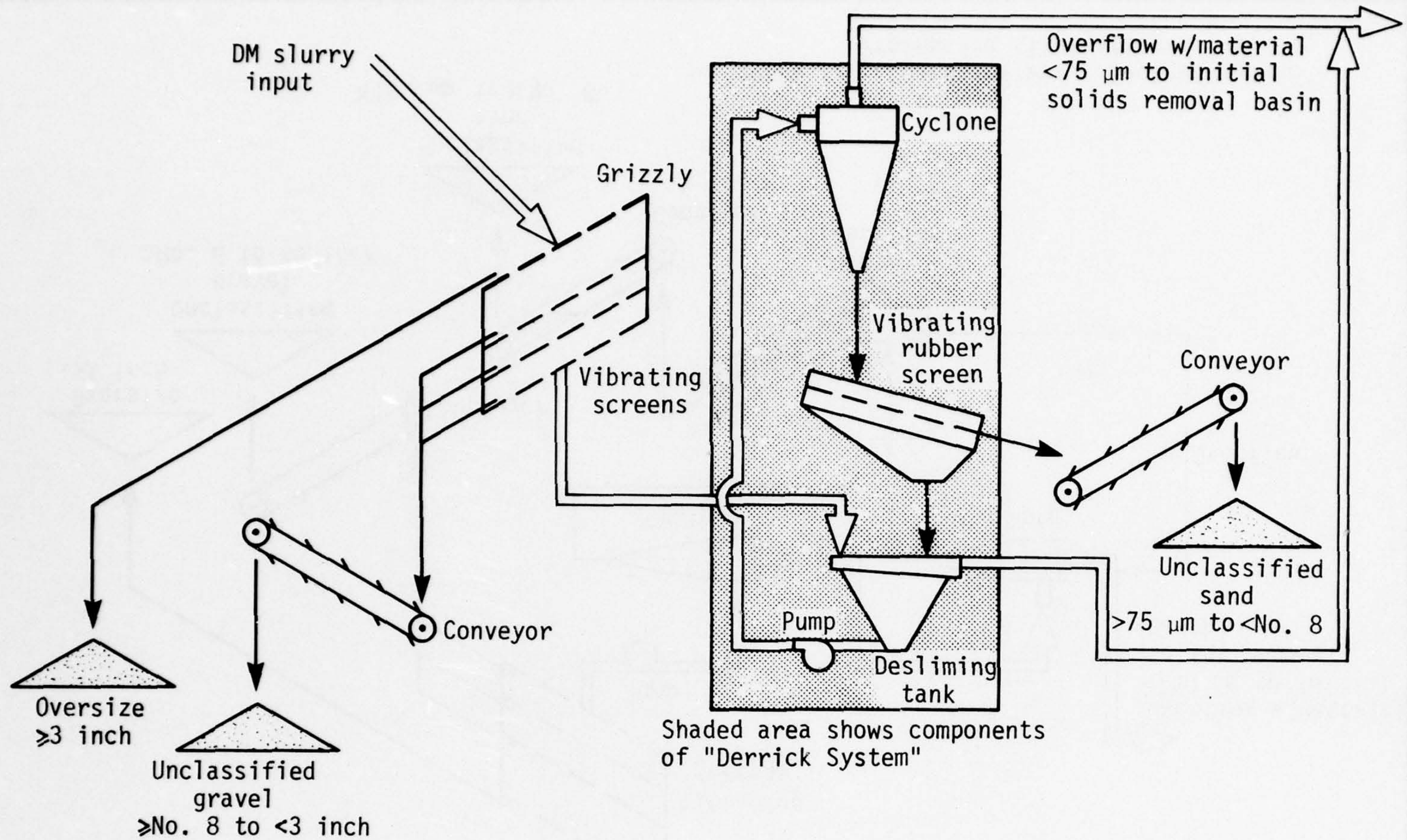
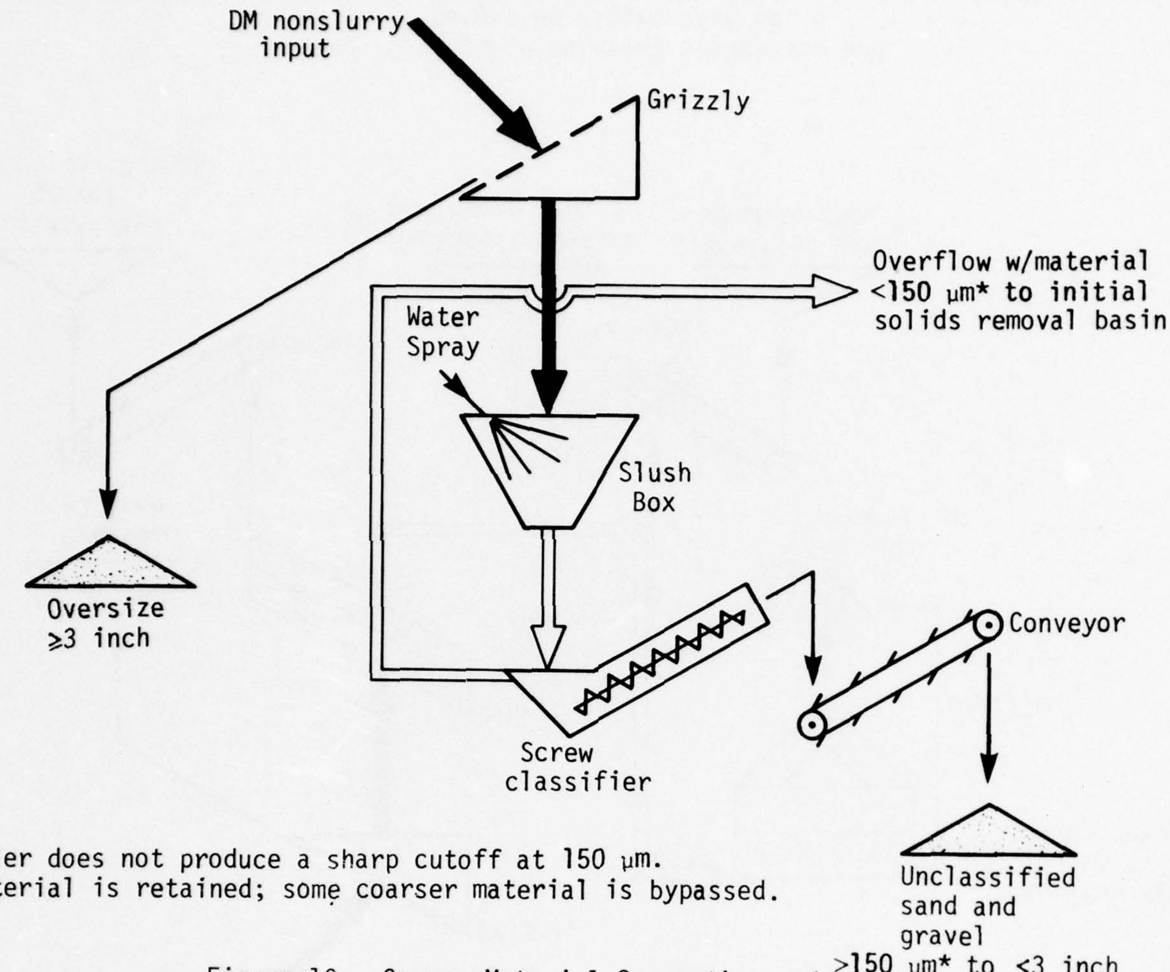


Figure 18. Coarse Material Separation and Processing Alternative No. 6



*Screw classifier does not produce a sharp cutoff at 150 μm.
Some finer material is retained; some coarser material is bypassed.

Figure 19. Coarse Material Separation and Processing Alternative No. 7

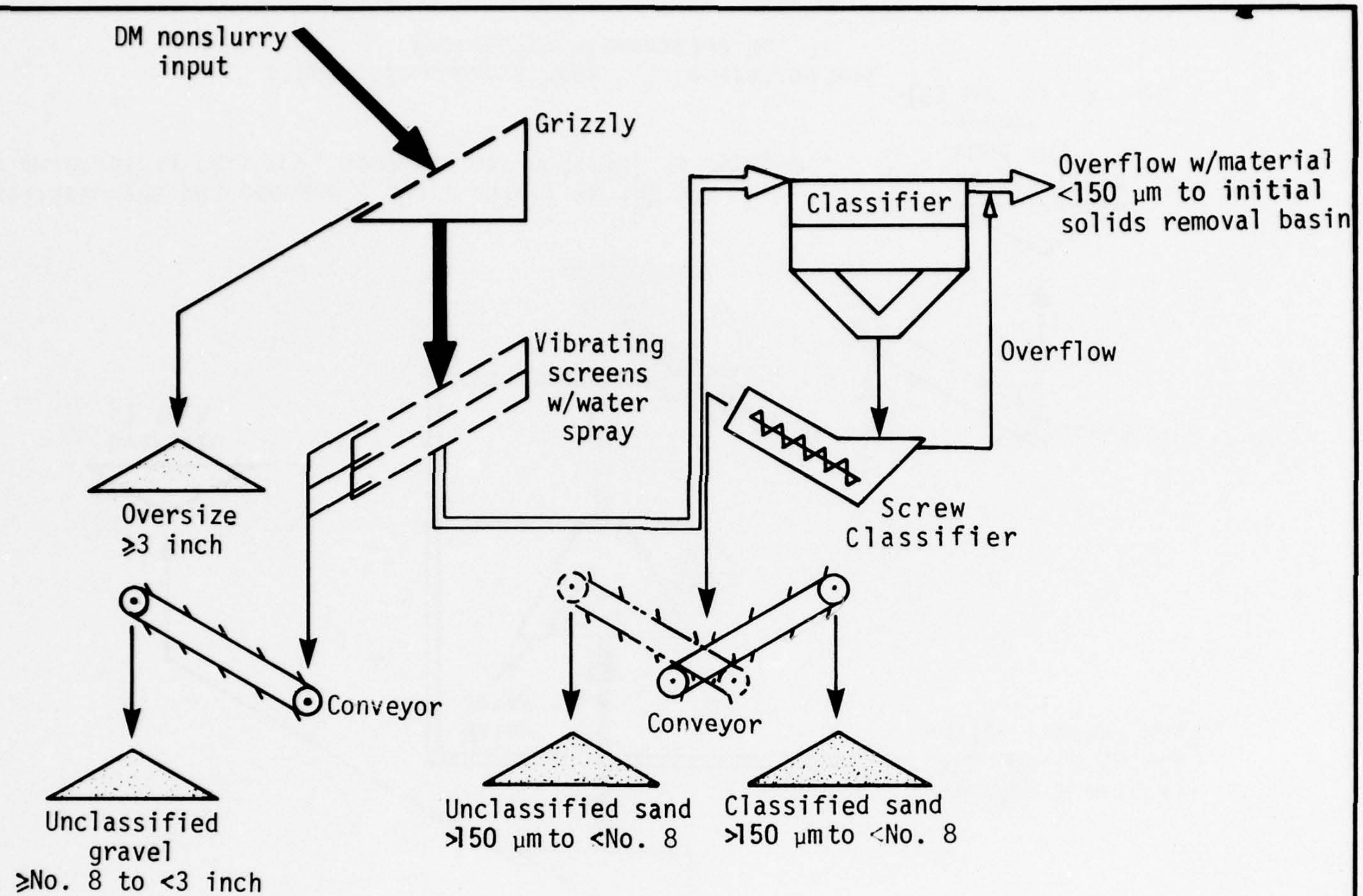


Figure 20. Coarse Material Separation and Processing Alternative No. 8

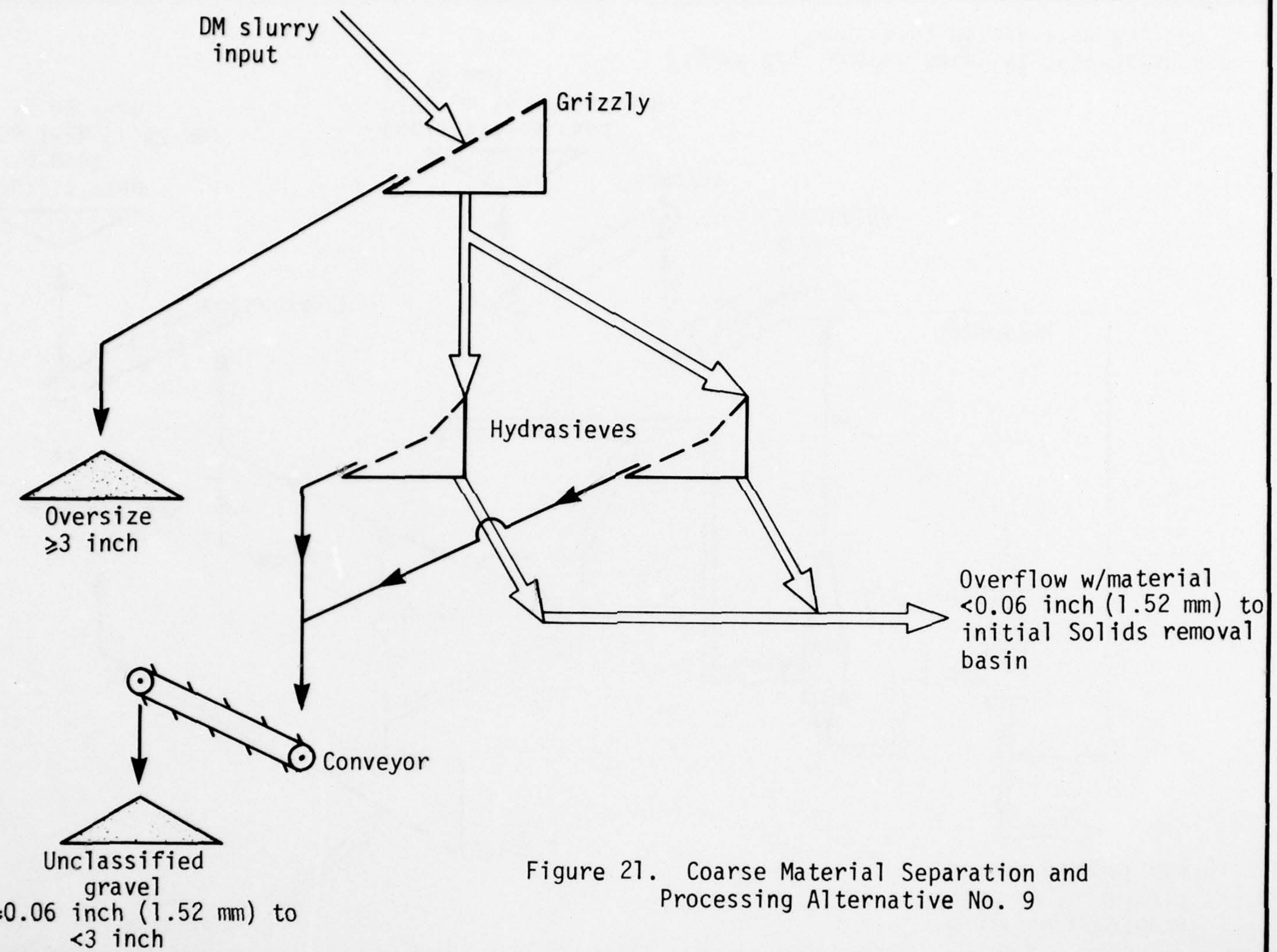


Figure 21. Coarse Material Separation and Processing Alternative No. 9

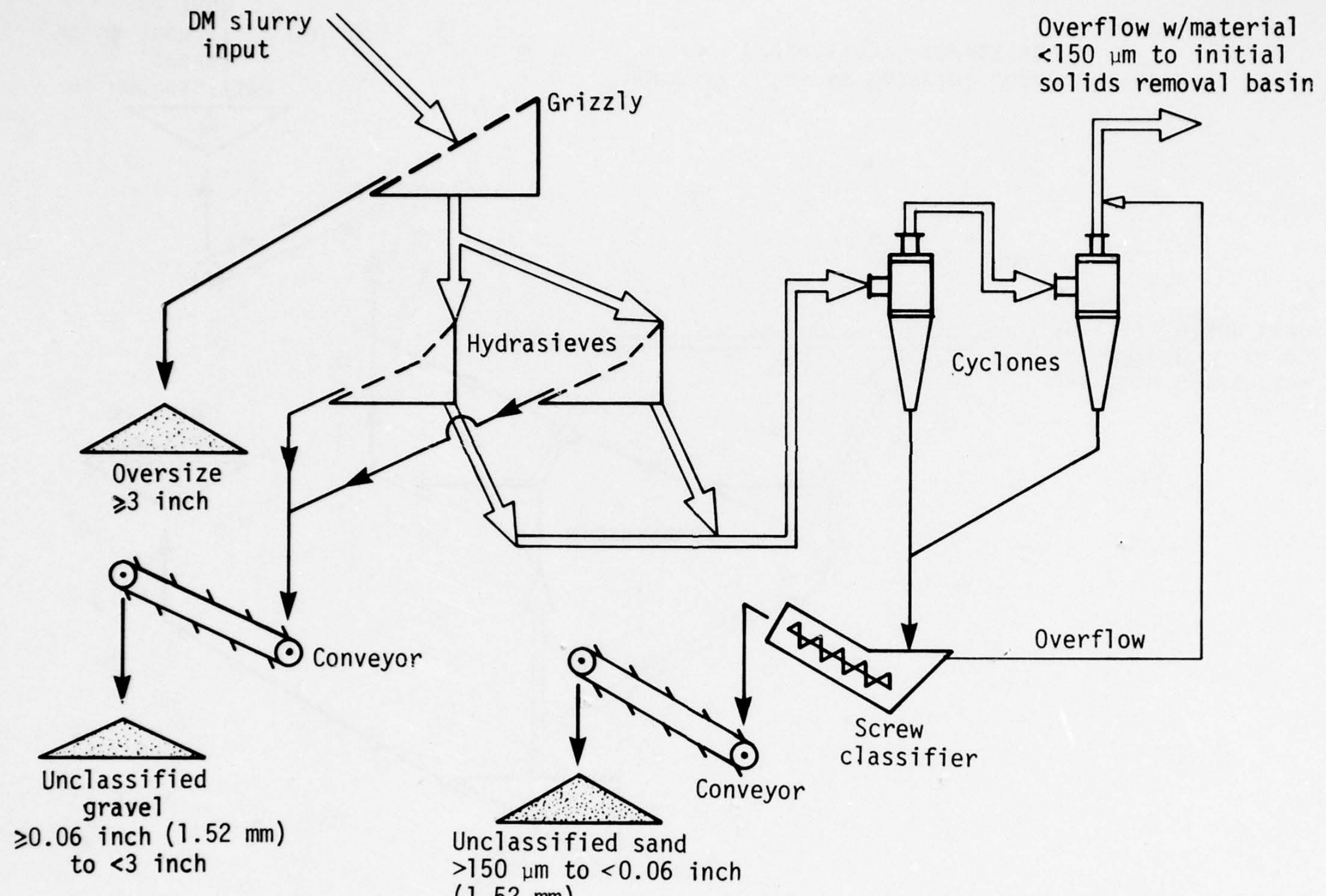


Figure 22. Coarse Material Separation and Processing Alternative No. 10

In pumping operations where raw material to be processed contains oversize material, the scalping-type pump box is recommended. This type of pump box not only reduces the line velocity of aggregate-laden water to proper flow for operations following, but also scalps out oversize material which would be detrimental to the screening operation. The inside of the scalping-type pump box if fully lined with replaceable abrasion-resistant steel plate for longer life of box. Diamond head alloy steel tapered grizzly stock is used to assure maximum wear resistance and avoid clogging (see illustration below). Boxes can be furnished with various sizes of grizzly opening or are available without grizzly if desired. Scalping-type pump boxes are available in sizes to handle material from a wide range of pump sizes.

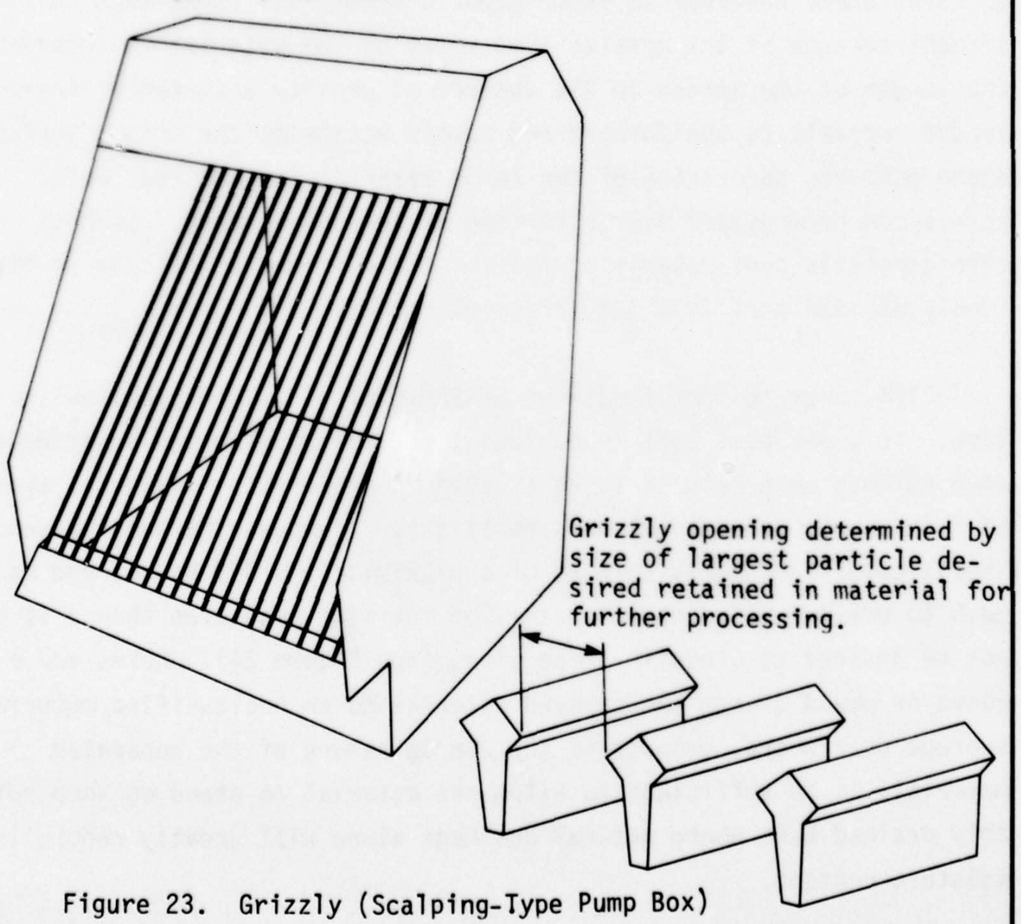
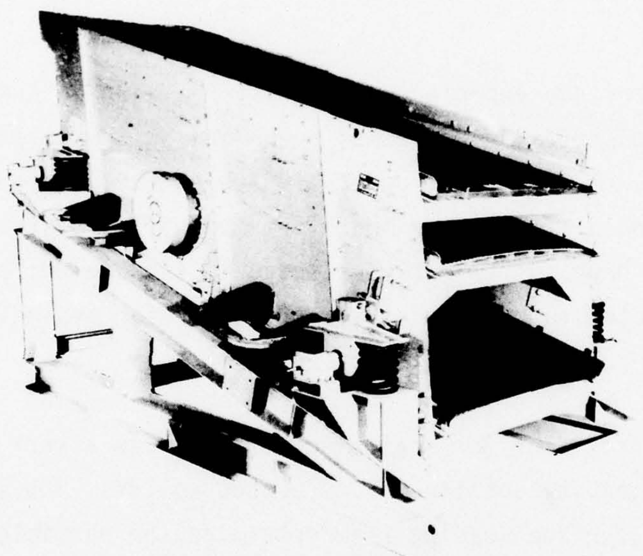


Figure 23. Grizzly (Scalping-Type Pump Box)

increasing the effectiveness of the screening operation. The desired vibratory motion is imparted to the screen by an eccentric rotating mechanism. By arranging for the impulses to be applied at the resonant frequency of vibration of the screen, these machines can be operated with very low power consumption and with only small reaction forces transmitted to their supporting structures. Typical amplitudes and frequencies of vibrating screens--both inclined and horizontal--are 0.1-0.5 inches and 900-1200 cycles per minute.

153. Most vibrating screens are mounted in series on a steel base frame and inclined downwards from the feed end, typical inclinations ranging from 12° to 18°. Horizontal screens, which are generally used in cases where headroom is restricted, are more efficient than inclined screens because of the greater time spent by the material in traversing the length of the screen in the absence of gravity assistance; movement is due entirely to the forward and upward motion of the screen surface.[32] Where complete separation of the large material is required, water sprays can be provided over a portion of the screen deck. Such an arrangement is particularly useful for the elimination of clay or other finely divided dirt from the larger particles.

154. Screen specifications in terms of width, length, inclination, etc., are best left to equipment manufacturers whose experience with various materials is to be trusted in preference to figures arrived at from purely theoretical considerations. However, the basic assembly should consist of three screens of approximately 3/8", No. 4, and No. 8 mesh to prevent blinding (clogging) of the fine mesh even though it may not be desired to classify these sizes (see Figure 24). Chutes and a conveyor would direct the removed material to an unclassified material storage pile where, because of the coarse nature of the separated material, it is sufficient to allow the material to stand on some suitably drained base where natural drainage alone will greatly reduce the moisture content.



5-foot x 14-foot triple-deck vibrating screen

Courtesy of Seco Screen Equipment Company

Figure 24. Vibrating Screen Unit

Hydrasieve

155. The Hydrasieve consists of a wedge wire screen with changing inclination (see Figure 25). Influent enters the headbox and overflows onto the upper portion of the screen, where most dewatering occurs. Solids mass on the screen's middle portion where the inclination is less and additional drainage occurs. Solids stop momentarily on the bottom portion of the screen, which is flattest, encouraging still further drainage; the solids are displaced from this portion of the screen by oncoming solids.[33]

156. Hydrasieve experience primarily has been in the wastewater field. Little quantitative work has been done on the solids loading capacity of a Hydrasieve, but, generally speaking, for good performance the influent should be dilute enough for smooth flow over the weir. Work to date has not been sufficiently extended to include DM; pilot studies should be conducted to provide a reliable basis for design.

Classifier

157. A classifier (or scalper-classifier) is a tank which slows flow to permit gravity settling of suspended solids. The surface area of the tank and surface loading rate determine the particle sizes that will be removed.* Large, heavy particles settle near the feed end; small, light particles settle near the overflow end. In this fashion, the settling material is "separated" into families or grades of approximately the same sized particle. Multiple discharge valves along the V-shaped bottom of the tank permit the operator to draw off one or more sizes at a time (see Figure 26) to produce spec products (e.g., ASTM Fine Aggregate). Excess material in any size range is drawn off and placed in a separate pile as waste or useful non-spec material.

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* These units do not produce a sharp cutoff at a particular particle size. Some finer-grained material is retained; some coarser-grained material is bypassed.

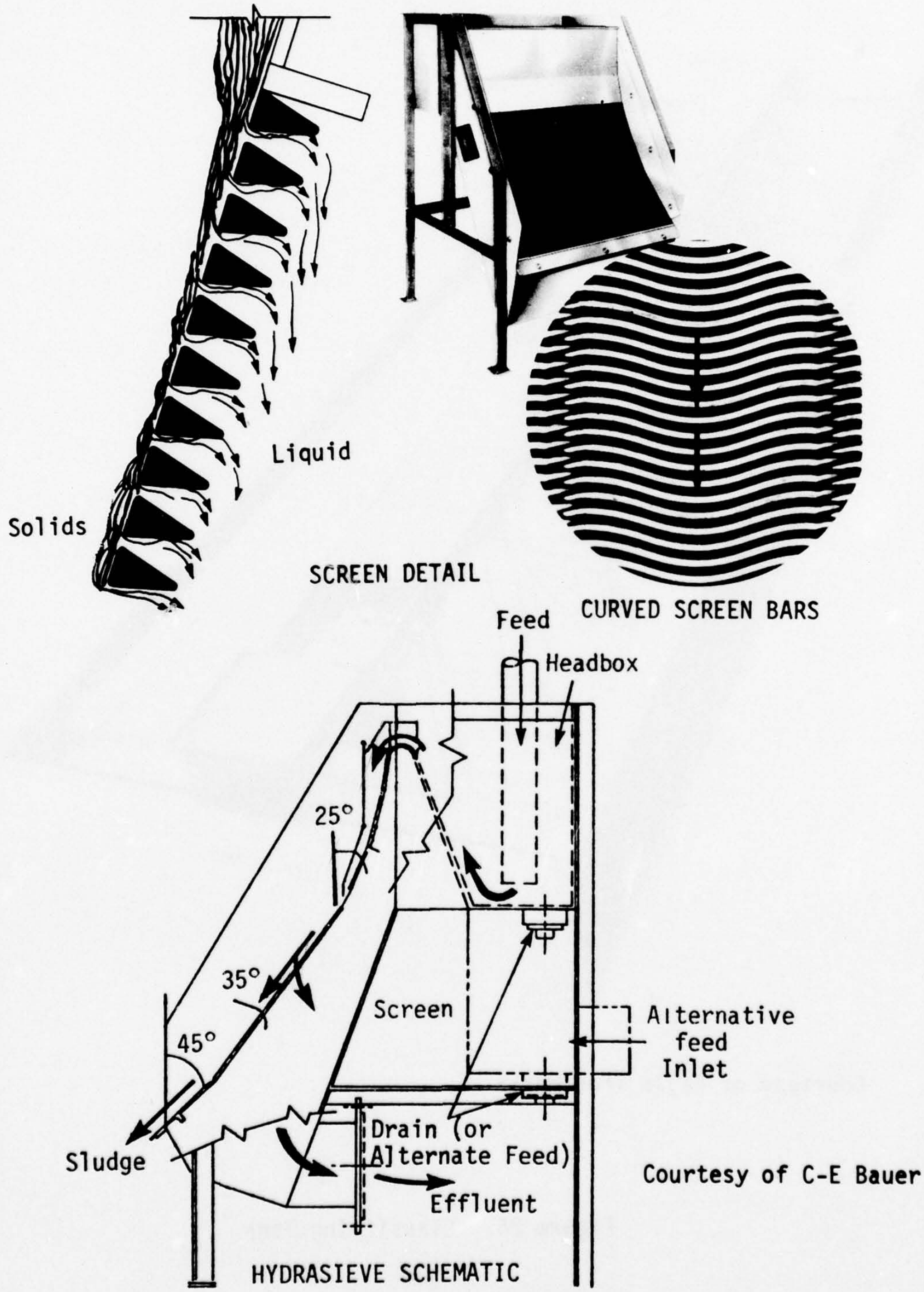
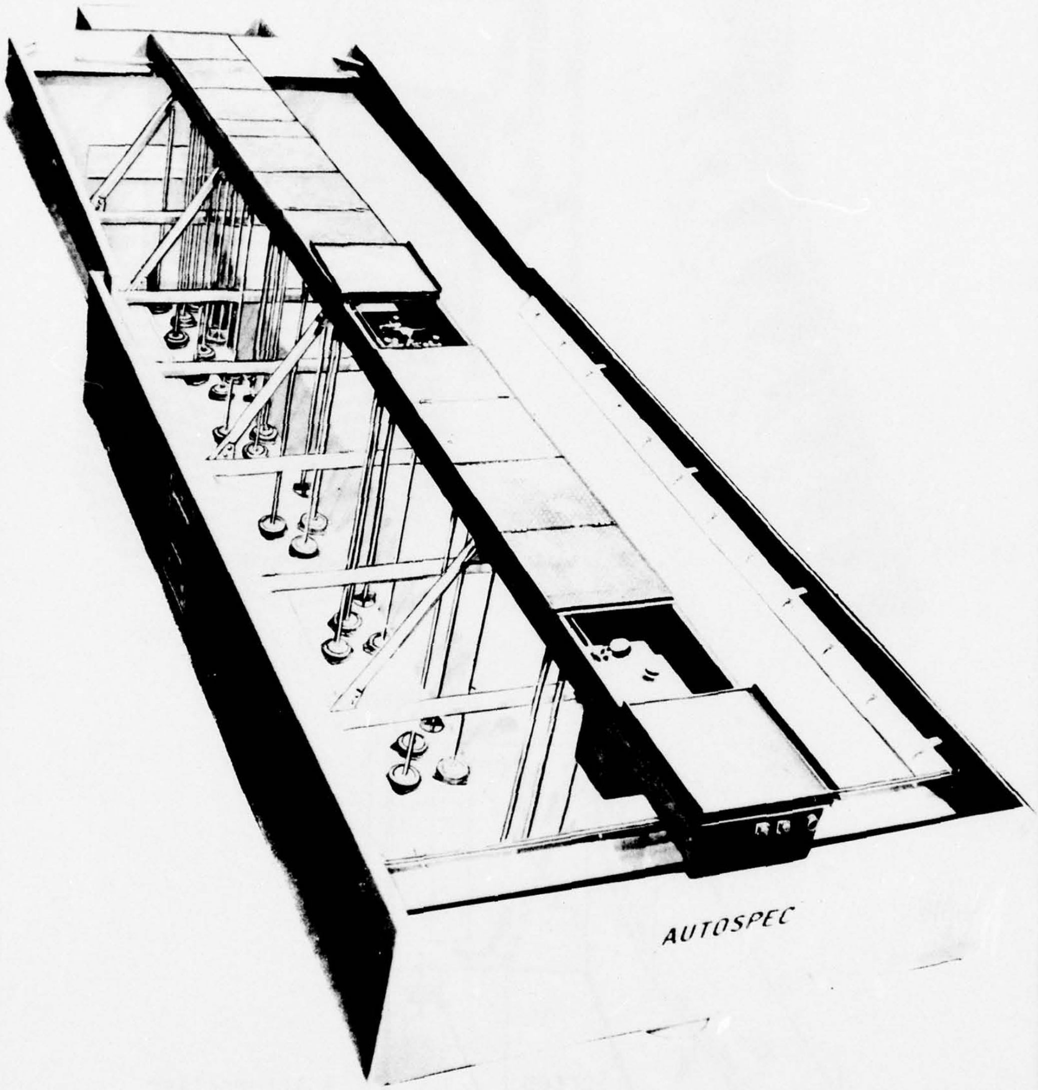


Figure 25. Hydrasieve



Courtesy of Eagle Iron Works

Figure 26. Classifying Tank

158. Manufacturers' catalogs recommend a surface loading rate of 15 gpm/ft^2 to retain >150-μm material, assuming a low silt content in the slurry. A high silt content requires the addition of clean water to prevent silts from clogging and thereby reducing the capacity of the classifier. Slurry from a secondary dredge serving a primary basin has a higher percentage of coarse material and satisfies the low silt condition. However, if the CMSP equipment is fed directly from the primary dredge or via a secondary dredge handling DM bottom-dumped from a hopper dredge or barge, a high silt content situation and the requisite supplemental water system is possible. Equipment manufacturers cannot specify a universally applicable upper silt limit. They recommend that tests be run with the material to be processed in order to ascertain the need for and capacity of a supplemental water system.

159. For a multiple-unit installation, splitter tanks are used to distribute the flow and cross flumes are used to collect the solids from the regular flumes. The collector flumes permit use of a small number of large capacity screw classifiers. Typical installations ranging from permanent to portable are shown in Figures 27-29. Note that since applications of classifiers to date have not been sufficiently extended into the DM processing field, pilot studies should be conducted to provide a sound basis for design.

Clarifiers

160. Clarifiers differ from classifiers only in that the former do not reblend the settled material to meet specific gradation requirements. A single set of valves is adequate to draw off the material as it accumulates. When settled material builds up to a certain point, level sensors activate a valve-opening mechanism. The drawn off material typically contains 30 percent water and is usually chuted to a screw classifier for further dewatering. As with classifiers, applications to date have not been sufficiently extended into DM processing; pilot studies should be conducted to provide a sound basis for design.

This drawing depicts an operation capable of producing four products--two gradations of ≥No. 8 mesh material and two grades of sand. This particular plant is producing concrete sand and mason sand, plus a third by-product consisting of excess material after production of the two sands.

To produce two sand products, such as concrete and mason sand simultaneously, the plant would screen out everything larger than No. 8 mesh. This is because mason sand specifications call for 100% passing the No. 8 mesh screen; concrete sand calls for 95-100% passing the No. 4 mesh screen or 100% the 3/8 screen.

A portion of the classified semi-dewatered <No. 8 mesh material from the classifier is directed to the mason sand screw classifier for finish washing and dewatering. The concrete sand screw classifier also receives a classified <No. 8 mesh feed. However, to obtain the correct percentage of <3/8 or <No. 4 to ≥No. 8 mesh material required in concrete sand, a <3/8 to ≥No. 8 mesh metering bin with controls and chute has been incorporated in this installation. The metering bin is fed from the bottom deck of the vibrating screen and this bin will feed the correct percentage of material into the concrete sand screw classifier. Surplus from the bin is directed to the coarse material. The metering bin system affords positive control of top size material in the concrete sand and also permits a <No. 8 mesh feed to the scalping-classifying tank. This, in turn, affords a top size control in the mason or asphalt sand product.

Courtesy of Eagle Iron Works

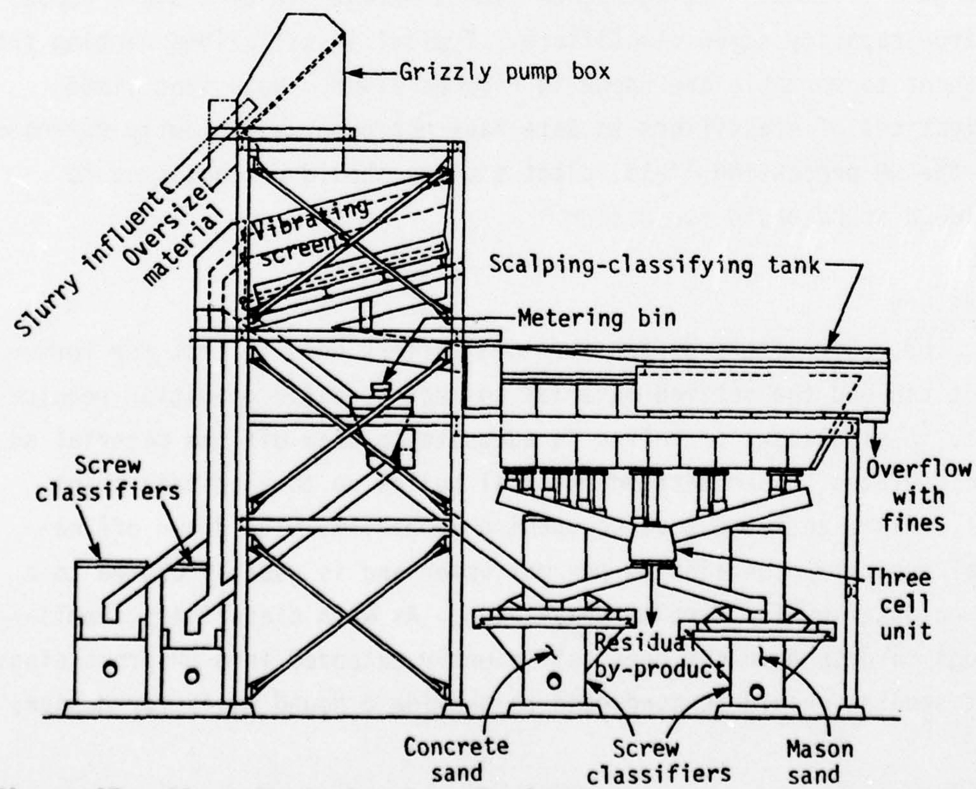
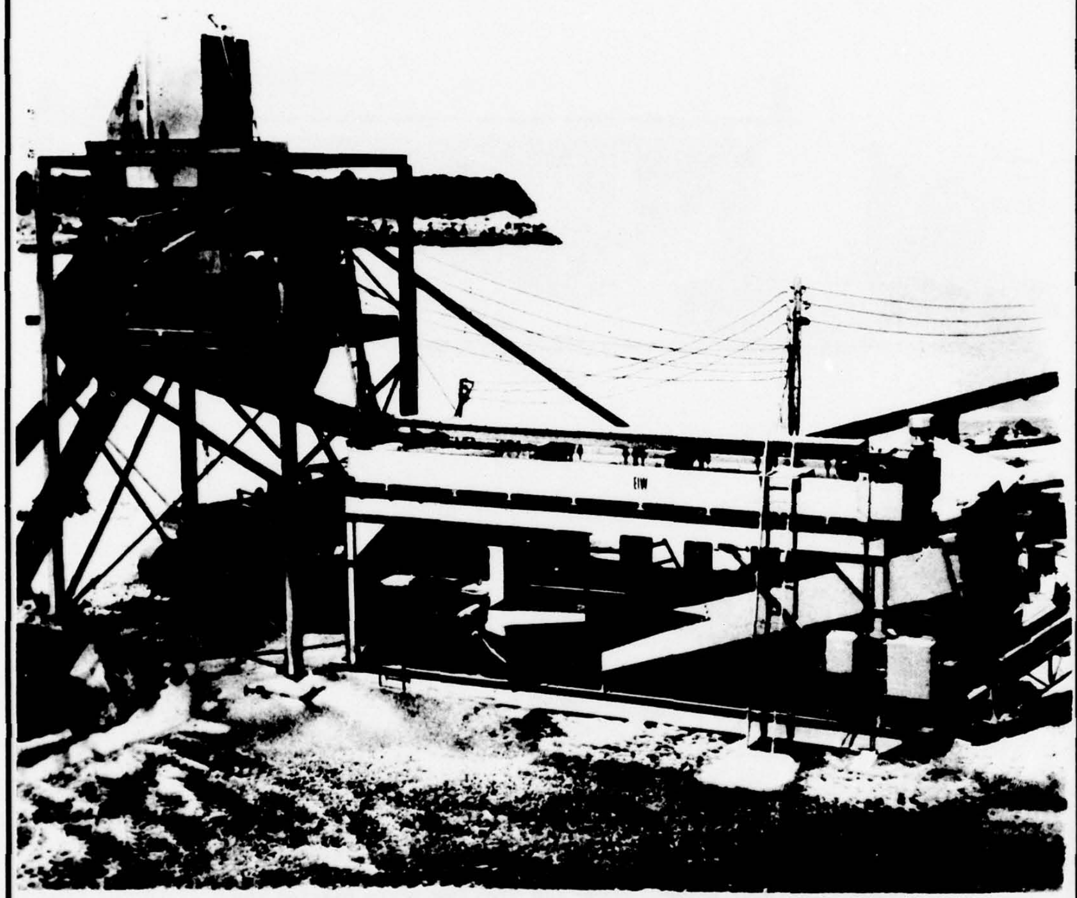


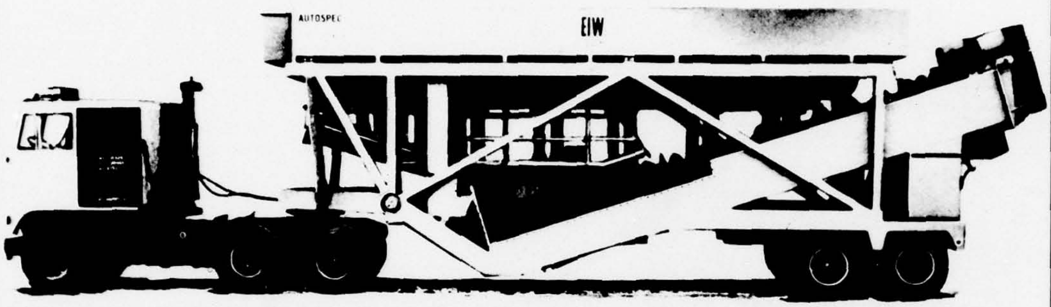
Figure 27. Plant Producing Four Products

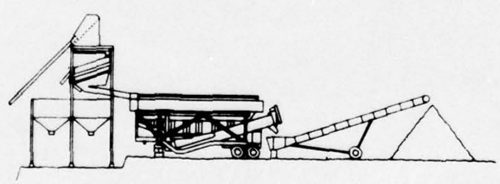


Semi-portable scalping-classifying unit is skid-mounted for easy relocation.

Courtesy of Eagle Iron Works

Figure 28. Semi-Portable Classifier Installation





The above installation incorporating a portable classifier can handle the output from a hydraulic dredge. Pump box with integral grizzly bars is mounted above a vibrating screen in a semi-portable sectionalized structural tower. Water and fine aggregate passing the vibrating screens are flumed to the portable classifier which can produce clean, classified sand of two different gradations.

Courtesy of Eagle Iron Works

Figure 29. Portable Classifier Unit

Circular Thickener

161. The conventional thickening tank (or thickener) is a cylindrical tank of steel or concrete construction in which suspended material is allowed to settle. The modern thickener (Figure 30) continuously removes sediment via a central discharge outlet in the base, while supernatant overflows into a peripheral launder. The feed to the thickener is introduced in the center of the tank below water level by any of the number of proprietary mechanisms designed to give good distribution without creating currents which would interfere with the settling process and cause contamination of the overflow. A radial arm or number of arms either curved in plan view or carrying suitably arranged deflector plates slowly rotates just above the level of the bottom of the tank (which usually slopes down toward the center) and drags the sediment to the center of the tank. Here, the sediment (in the form of a thick sludge) is continuously withdrawn by a pump.

162. The dimensions of thickeners are determined by the solids concentration and rate of feed for the suspension to be treated, the size distribution and density of the particles, the effect of flocculating agents if used,* and the required condition of the overflow and the settled solids. Common depths of thickeners are 6-20 feet.[32] Diameters most frequently are in the range of 40-80 feet; however, thickeners as large as 325 feet in diameter have been constructed. In sizes up to 85 feet in diameter, the driving mechanism is attached to the shaft at the center of the tank. For very large diameters or where extremely viscous sediment is produced, a traction type of thickener is used; the rotating scraper arm is supported by means of a radial truss which is supported on motor-driven wheels running on a rail laid around the edge of the tank.

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* Flocculating agents would not be used in a CMSP facility.

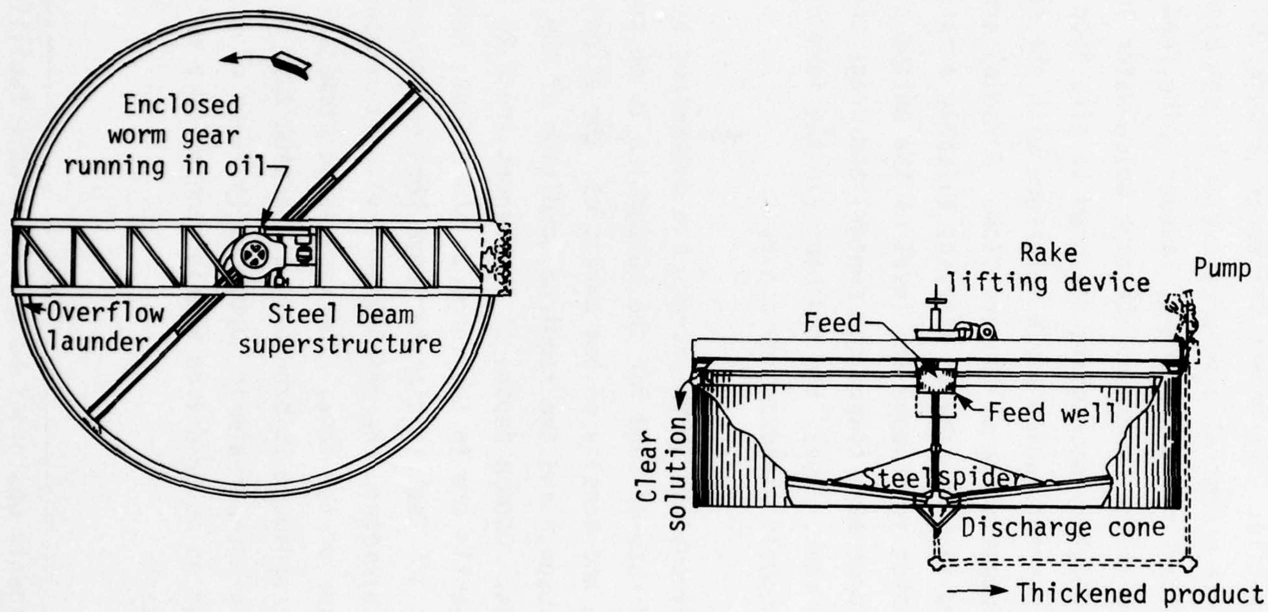

Figure 30. Circular Thickener[26]

163. No attempt is made to classify the material in this tank. In the applications shown in Figures 12 and 16, the overflow would contain <150-μm* material which would be bypassed to the Initial Solids Removal basin. The underflow sludge would pass to screw classifiers for further dewatering and then directed by conveyor to a stack of unclassified sand. Circular thickeners commonly used in the minerals processing industry might be used for DM application. However, thickeners have not been used at the flow rates, concentrations, and total solids handling rates required for CMSP. Therefore, pilot studies should be conducted to provide a sound basis for design.

Screw Classifier

164. A screw classifier elevates the coarser materials removed by coarse/fine separation equipment via a large diameter screw (see Figure 31). This action agitates the sand and removes adhering fine materials and organics. Counterflowing flush water helps to wash the fine particles off the sand grains. The material discharged from the solids unloading end of a screw classifier has a relatively low moisture content and will form a stack. This material can be readily handled on standard belts operating at normal speeds and at inclinations of 16 to 18 degrees. Overflow containing fines and organics passes to the Initial Solids Removal basin.

Hydrocyclones

165. A hydrocyclone (cyclone) is a conical device employing centrifugation to remove suspended solids (see Figure 32). The slurry enters the cyclone through a tangential inlet at a relatively high velocity (about 50 fps). As the fluid spirals downward, centrifugal

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* Circular thickeners do not produce a sharp cutoff at a particular particle size. Some finer-grained material is retained; some coarser-grained material is bypassed.

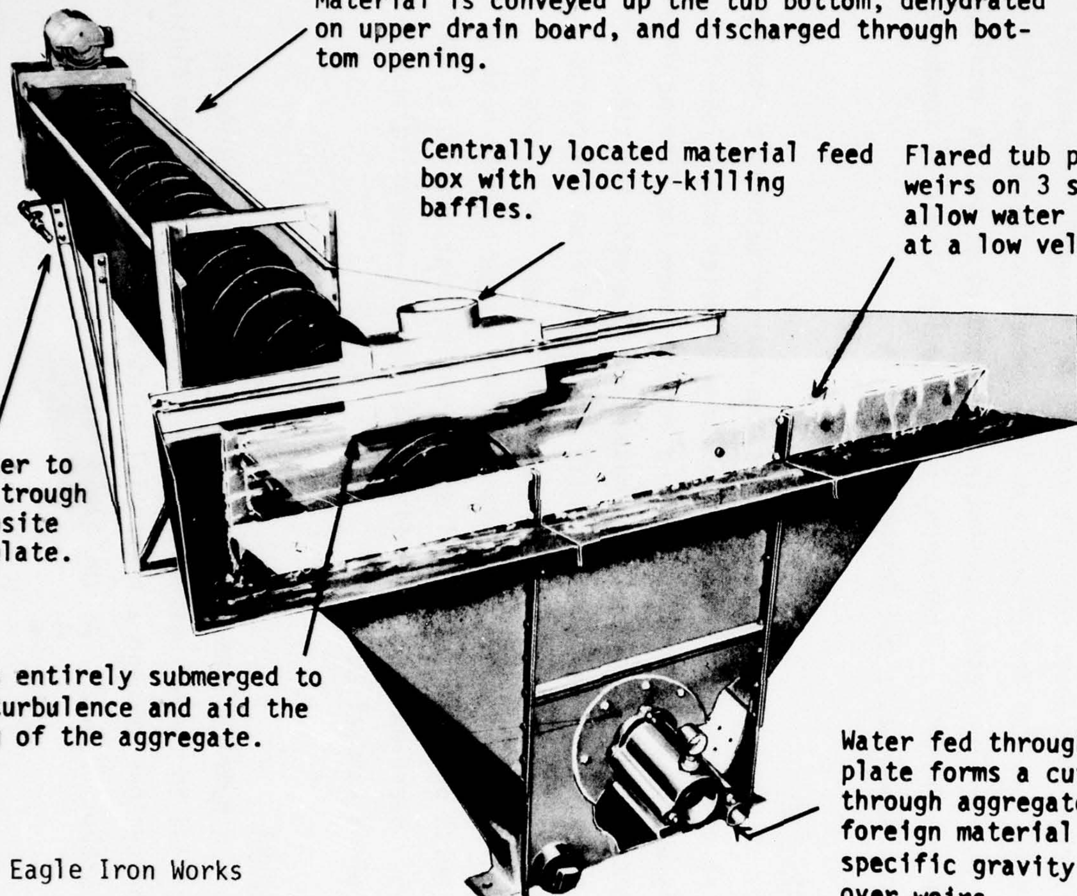
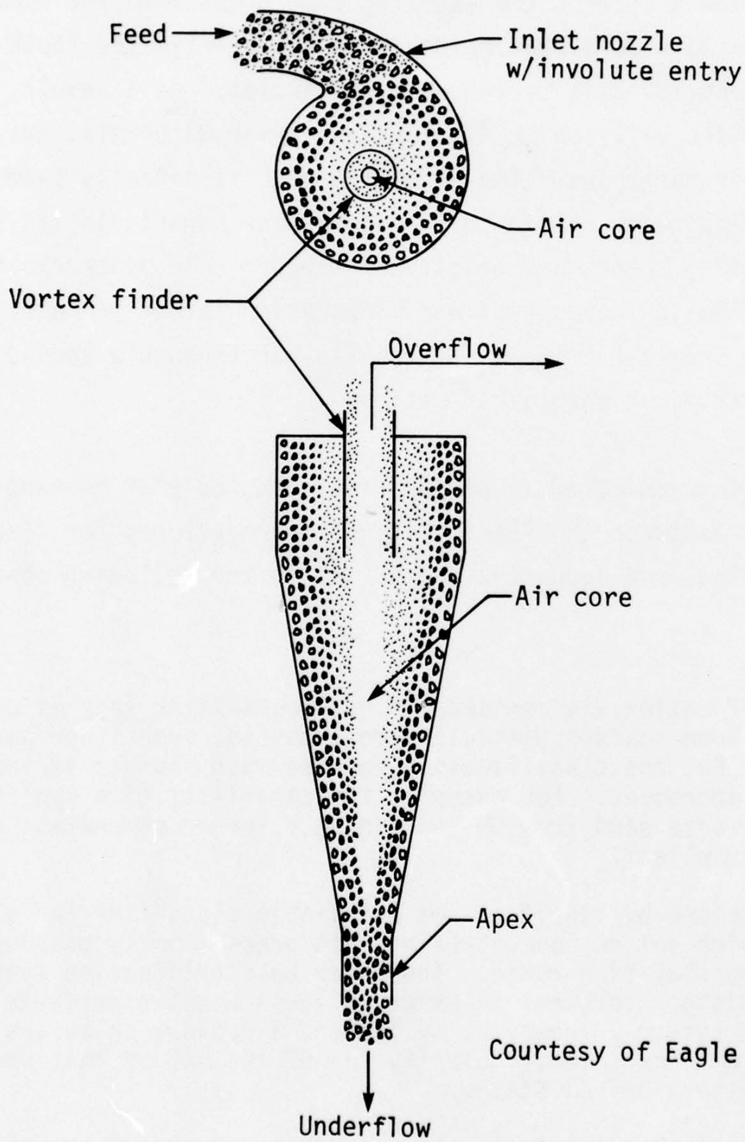


Figure 31. Screw Classifier



Courtesy of Eagle Iron Works

Figure 32. Hydrocyclone

acceleration causes denser and coarser-grained particles to migrate toward the outer wall; lighter and finer-grained particles remain nearer the center of the unit. As the swirling flow drops into the converging conical section, a secondary flow develops and carries the fluid inward and upward around the axis to the overflow outlet. As a result, the underflow from the wall region is rich in coarser materials; the overflow is rich in finer particles. The underflow rate is normally 5-30 percent of the inlet flow rate. Fluid/solid separation characteristics are dependent on size, shape, and density of solids; cone geometry; fluid viscosity; and solids concentrations. Separation is not perfect; therefore, overflow from a cyclone is frequently run through a second cyclone for further clarification/classification.[30]

166. Tests conducted in conjunction with the DMRP on samples of actual DM[30] to evaluate the feasibility of hydrocyclones for classifying, clarifying, and concentrating DM led to the following conclusions:

- Classification via cyclones (i.e., coarse/fine separation) is not perfect. Some coarser particles are bypassed; some finer particles are retained. But the classification becomes much sharper as the design particle size increases. For example, the capability of a cyclone to recover medium-size sand from DM containing a larger percentage of fine silt appears excellent.

- The cyclone by itself is not a feasible classifier for slurries containing a high solids concentration with predominantly pseudoplastic material in the clay-size range. There may be clarification systems involving multistep processes in which cyclones would contribute (such as the Derrick system). However, by itself, a cyclone or series of cyclones will not sufficiently clarify the DM typical of that produced in the southeastern United States.

- Tests with varying influent solids concentrations showed that increasing the inlet solids concentration has a very deleterious effect on the clarification performance of the units. High concentrations of small particles encourage pseudoplastic slurry behavior and cause

hindered settling in the cyclone. A cyclone or cyclone series is a feasible concentrator of DM when influent solids concentrations are less than about 10 percent by weight.*

- A practical upper limit for underflow concentrations of fine-grained DM (including clays) appears to be about 53 percent by weight. During the test program, the maximum underflow solids concentration was about 50 percent by weight, which occurred with an influent concentration of about 12 percent by weight, the solids being clay.**

167. The referenced testing program did not consider the effect of adding flocculants to the slurry. Clarification efficiency for DM with a large silt/clay fraction could be increased significantly by causing fine-grained particles to agglomerate into larger equivalent particles. This operation would leave the separated coarse material with clay balls, however, and would probably be more of interest in cases where effluent clarification was of more importance than production of a clean, coarse fraction.

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* A 10 percent influent concentration might effectively restrict cyclone use to influent direct from the primary dredge or from a secondary dredge serving a holding basin. A secondary dredge in other applications is expected to have a slurry with up to 20 percent by weight. See the discussion on DM delivery means in the next section. Note, however, that information provided by hydrocyclone manufacturers on applications other than DM does not suggest that 10 percent is a significant breakpoint. The Derrick Manufacturing Corporation (see Paragraph 169) claims its cyclone can handle influent with up to 25 percent solids by weight. Literature from Heyl and Patterson Incorporated provides performance curves for their 14-inch cyclone with up to 18 percent solids and cites applications with concentrations up to 36.8 percent solids by weight. Obviously, further tests with DM should be conducted to resolve this issue.

** Again, information from manufacturers contradicts these test results. Derrick claims an underflow concentration (with vacuum) of 70 to 75 percent solids by weight. Heyl and Patterson show up to 78 percent in a typical application.

168. Because applications of cyclones to DM have been relatively limited to date and because of the cyclone's sensitivity to DM properties, influent concentrations, etc., before the District commits itself to a CMSP system based on hydrocyclones, equipment manufacturers should be supplied with DM samples for performance tests and to provide a sound basis for cyclone selection.

Derrick System

169. The Derrick Manufacturing Corporation has put together a bulk material dewatering system employing a combination of processes, including a hydrocyclone. This system (see Figure 33) comprises a desliming and feed regulating tank, a slurry pump, a vacuum-assisted cyclone fluid/solid separator, and a vibrating rubber dewatering screen. The Derrick system must be preceded by screens to limit the incoming particle size to approximately 1/4 inch. (The vibrating screens shown in Figure 18 remove to a No. 8 mesh, about 3/32 inch.) According to the manufacturer, the influent to the cyclone can have from 1 to 25 percent solids by weight. The cyclone has a vacuum applied to the underflow. This provides a thickened and classified underflow of >No. 200 mesh (75-μm) material with a very small amount (about 1 percent) of undersize retention.[31] With a material equivalent to ASTM Fine Aggregate, the underflow will be approximately 70 to 75 percent solids by weight. The underflow passes over a vibrating rubber screen for additional dewatering, yielding a product 80 to 82 percent solids by weight. A vacuum may also be applied to the lower portion of the vibrating rubber screen to draw off still more moisture, producing a product with about 86 percent solids by weight. The dewatered product is fed to a conveyor for stacking. The overflow with <No. 200 mesh material proceeds to the Initial Solids Removal basin.

170. Although the Derrick system has not been used in the DM processing field, data are available for sand and gravel production, chemical processing, and pollution control in instances where area was

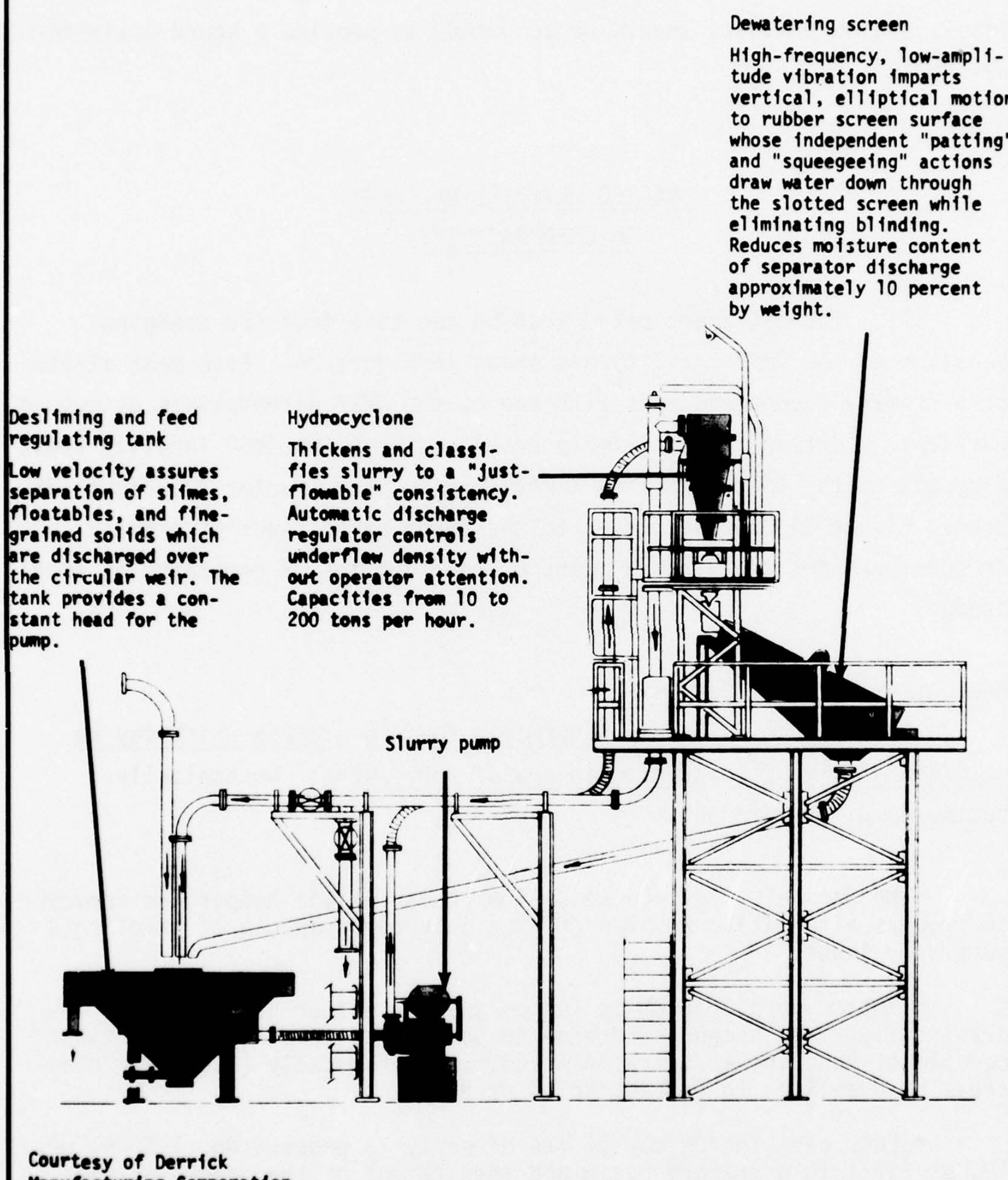


Figure 33. Derrick System

limited and costs for building and maintaining sludge ponds were high. Still, prototype tests should be conducted to provide a sound basis for design.

DREDGED MATERIAL DELIVERY TO CMSP FACILITY

171. The different paths that DM can take from the dredging location to the CMSP facility are shown in Figure 34. Each path starts at a primary dredge and ends with one of the CMSP alternatives discussed earlier. Overflow from a primary basin and from the CMSP facility feeds directly to the Initial Solids Removal basin (see Chapter 7). Figure 35 breaks Figure 34 down according to the three basic types of primary dredges and shows the various means of handling the DM generated by each dredge.

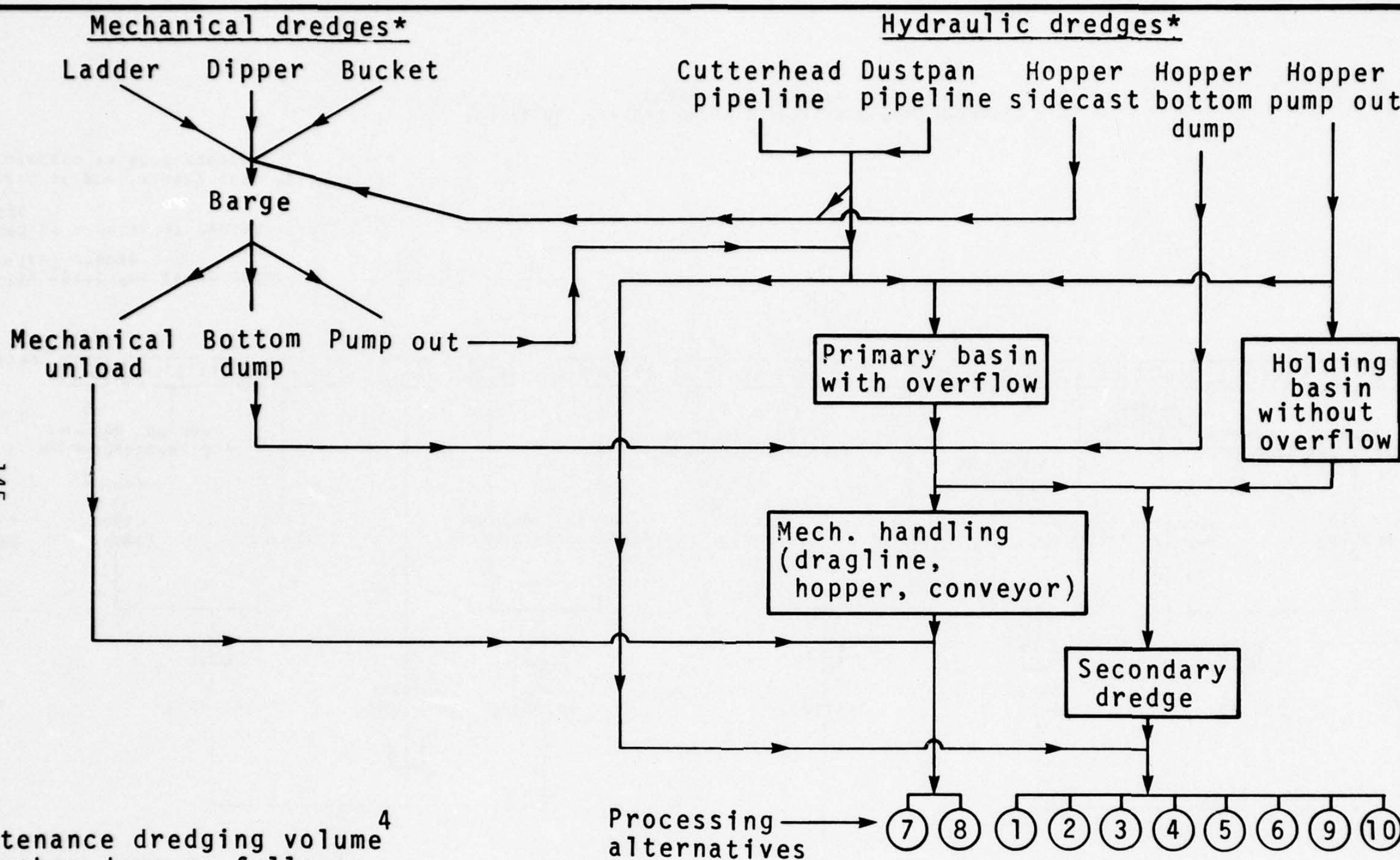
Mechanical Primary Dredges

172. Mechanical dredges normally feed to a barge which may be unloaded at the disposal site in any of three ways: mechanically, bottom dump, or pump out:

- Mechanical (e.g., bucket)--The DM is fed via hopper and conveyor to process alternative No. 7 or 8, the only ones capable of handling a nonslurry input.

- Bottom dump--The DM is fed on site in either of two ways: hydraulically via a secondary dredge to process No. 1-6, 9, or 10, those capable of handling a slurry influent; or mechanically (e.g., via clamshell or dragline) to process No. 7 or 8.

- Pump out--The DM may be fed directly to process No. 1-6, 9, or 10; or first to a primary basin and then to one of the processes via mechanical means (to No. 7 or 8) or secondary dredge (to No. 1-6, 9, or 10).



*Maintenance dredging volume[4] is broken down as follows:

. Mechanical dredges 1.5%
. Hydraulic pipeline dredges 69%
. Hopper dredges 24%
. Mixed mode 5.5%

Figure 34. Dredged Material Delivery to Coarse Material Separation and Processing Facility

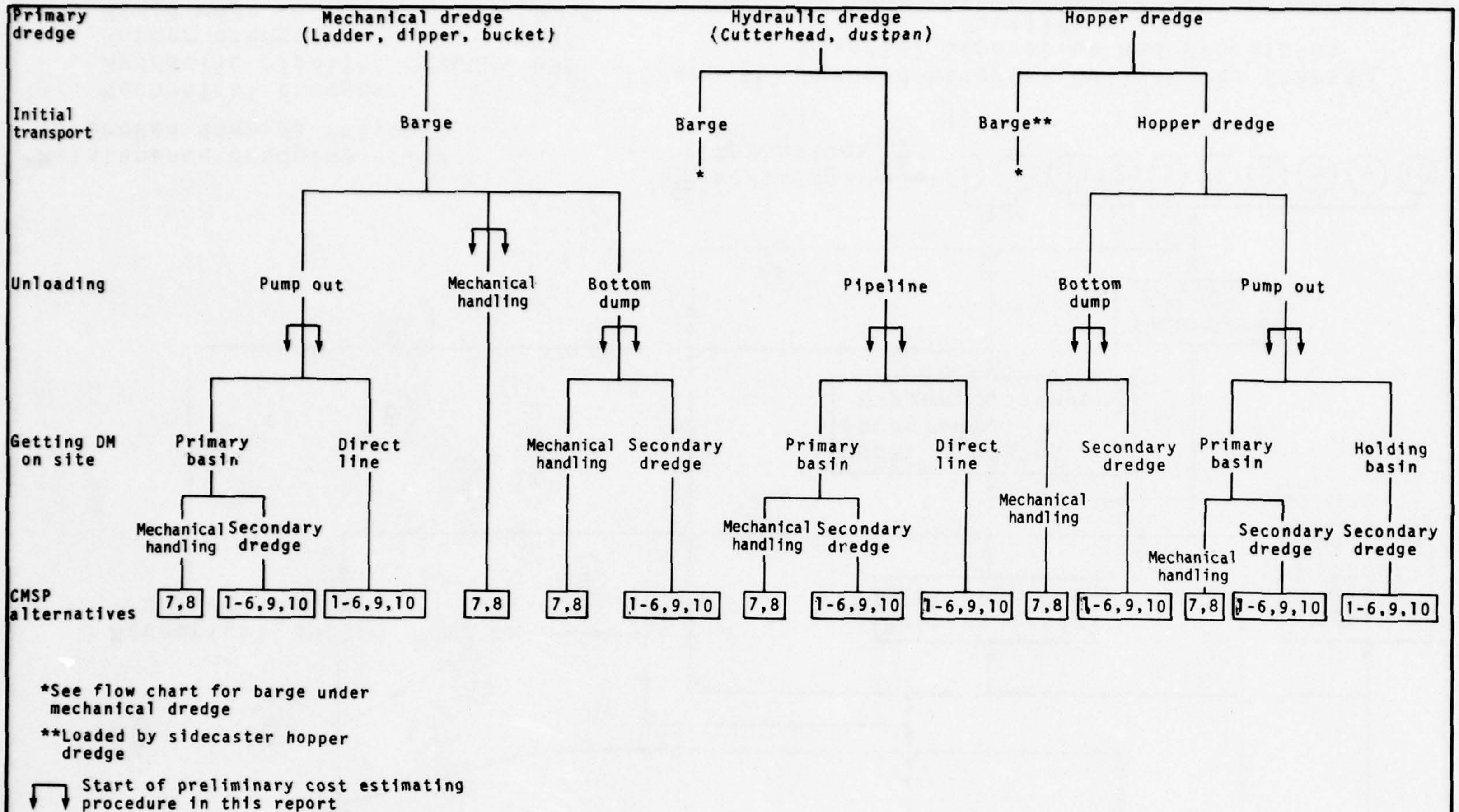


Figure 35. Dredged Material Movement from Primary Dredges to CMSP Facility

Pipeline Primary Dredges

173. A hydraulic pipeline dredge may load the DM onto a barge if, for example, a direct pipeline to the facility is not possible. In this case, the unloading and handling procedures in Paragraph 172 apply. If a direct pipeline is possible and economically preferable to barging, the DM slurry may be fed to the CMSP facility either directly or indirectly via a primary basin and thence to one of the processing alternatives via mechanical handling or a secondary dredge (see Figure 36.).

Hopper Primary Dredges

174. Material dredged via a hopper dredge may be transported to the CMSP facility either in the hoppers or via barges loaded by a sidecaster dredge. In the latter case, the barges are unloaded at the facility and the DM handled as described in Paragraph 172. DM delivered by hopper dredge may be:

- Bottom dumped--The DM is then rehandled via mechanical equipment or secondary hydraulic dredge to get it on site to the appropriate CMSP alternative (see Figure 37).

- Pumped out--The DM can be pumped to either a primary basin or a holding basin. The DM can be recovered hydraulically or mechanically from a primary basin, but only hydraulically from a holding basin, and fed to a suitable CMSP alternative (see Figure 38).

It should not be necessary to design a site to handle both bottom-dump and pump-out cases according to the logic diagram shown in Figure 39.

Primary Basin

175. A "primary basin" is used to reduce the flow rate and increase the concentration of coarse-grained materials reaching the CMSP facility, thereby reducing equipment costs while improving performance. Use of a primary basin does not, however, reduce the size of the ISR and FSR facilities. Indeed, when the sediment in the primary basin is recovered by mechanical equipment and reslurrified for CMSP their size

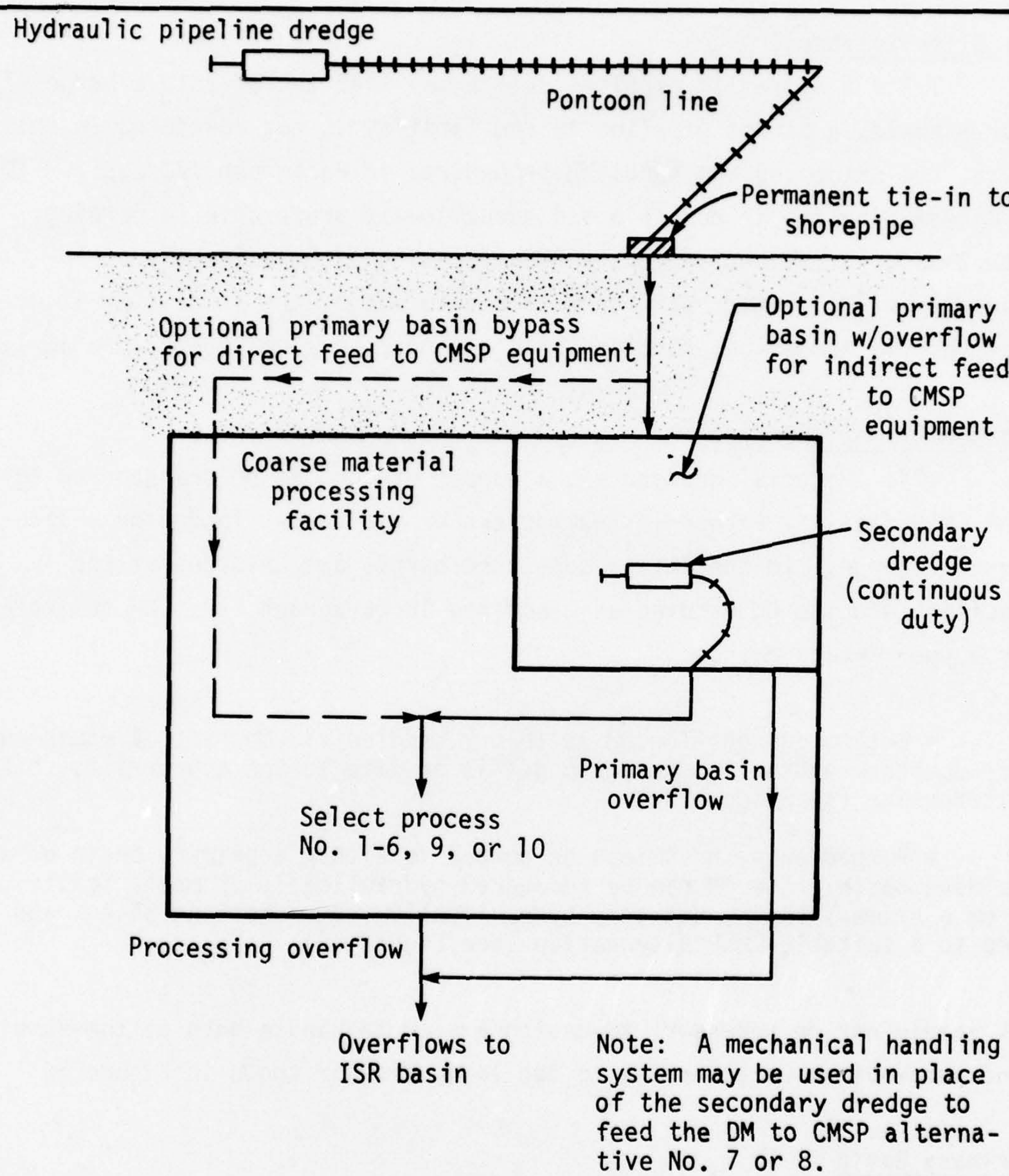
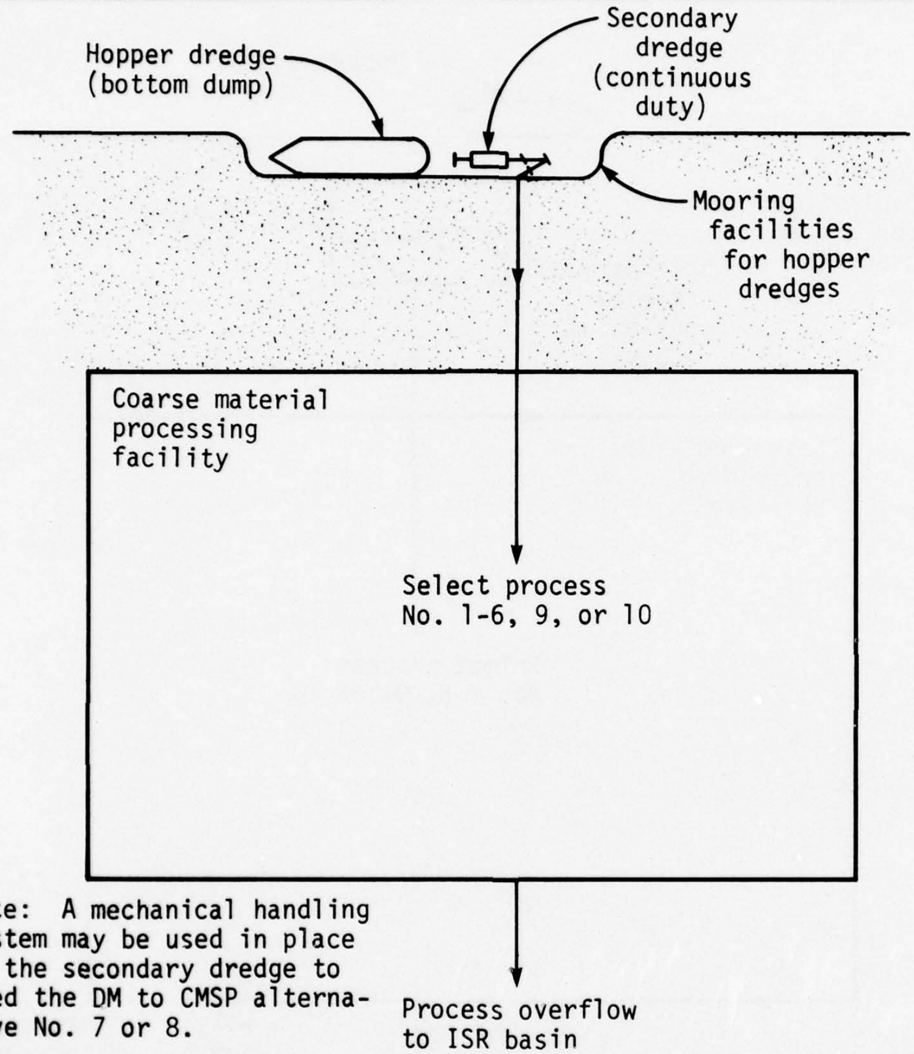


Figure 36. Pipeline Transport of DM to CMSP Facility



Note: A mechanical handling system may be used in place of the secondary dredge to feed the DM to CMSP alternative No. 7 or 8.

Figure 37. Hopper Dredge Bottom Dump of DM at CMSP Facility

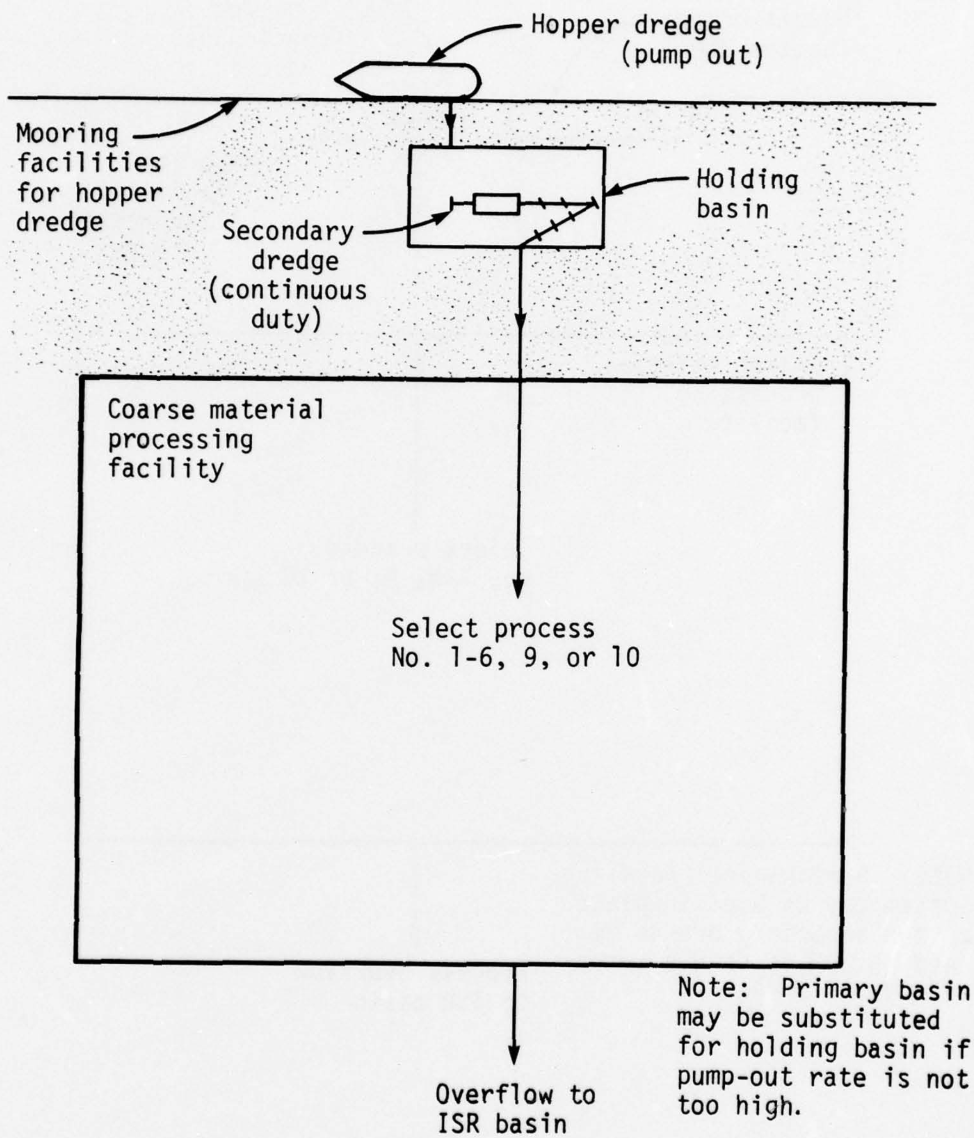
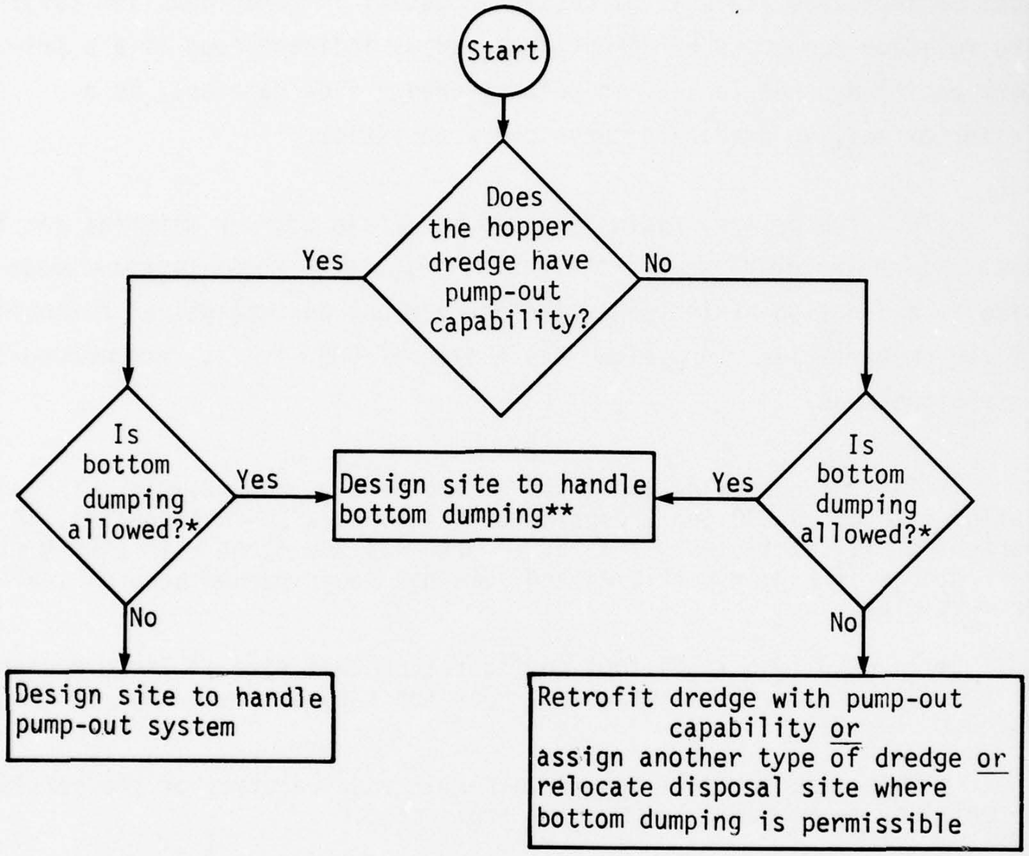


Figure 38. Hopper Dredge Pump Out of DM at CMSP Facility



*Environmental concerns might preclude bottom dumping.

** Generally it will be more advantageous to bottom dump than to pump out because:

- Bottom dumping cuts hopper dredge downtime tremendously.
- Bottom dumping alleviates the need for a primary basin or holding basin.

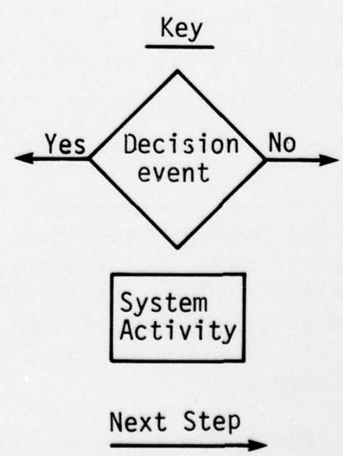


Figure 39. Hopper Dredge Bottom Dumping Versus Pumping Out

must be increased (this is discussed in detail in Paragraphs 198-199). The relative economics of direct feed versus indirect feed (via a primary basin) depends largely on primary dredge flow rate and, to a lesser extent, on gradation curve characteristics.

176. The primary basin is sized to retain coarser material and to bypass finer material to the ISR basin. Figure 40 shows primary basin size as a function of influent rate for various percentages of retention of 150-μm particles. A minimum basin size of 5000 ft^2 is recommended for most situations:

- This size retains most ≥150-μm* material. For example, with an inflow rate of 20,000 gpm (roughly equivalent to a 20-inch dredge), 88 percent of all particles sized 150 μm are retained along with even greater percentages of bigger particles and somewhat lower percentages of smaller particles.

- In a 50-foot x 100-foot configuration this size is large enough to provide satisfactory maneuvering room for a secondary dredge of the Mud Cat class. **

- This size is small enough to permit easy recovery of the settled material by mechanical equipment if preferable.

For the examples in this report, we have adopted a figure of ≥75 percent retention of 150-μm particles as a reasonable design level of performance for the primary basin. This value guarantees retention of sufficient material <150 μm to meet ASTM Fine Aggregate specifications (Table 8)

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* The primary basin does not provide a sharp cutoff at 150 μm. Some coarser material is bypassed; some finer material is retained. Undesirable fines that are retained and then fed into the CMSP equipment are processed out of the coarse material to a great extent and carried in the overflow to the ISR basin along with the overflow from the primary basin.

** For information on selection criteria of secondary dredges, see Paragraphs 191-194.

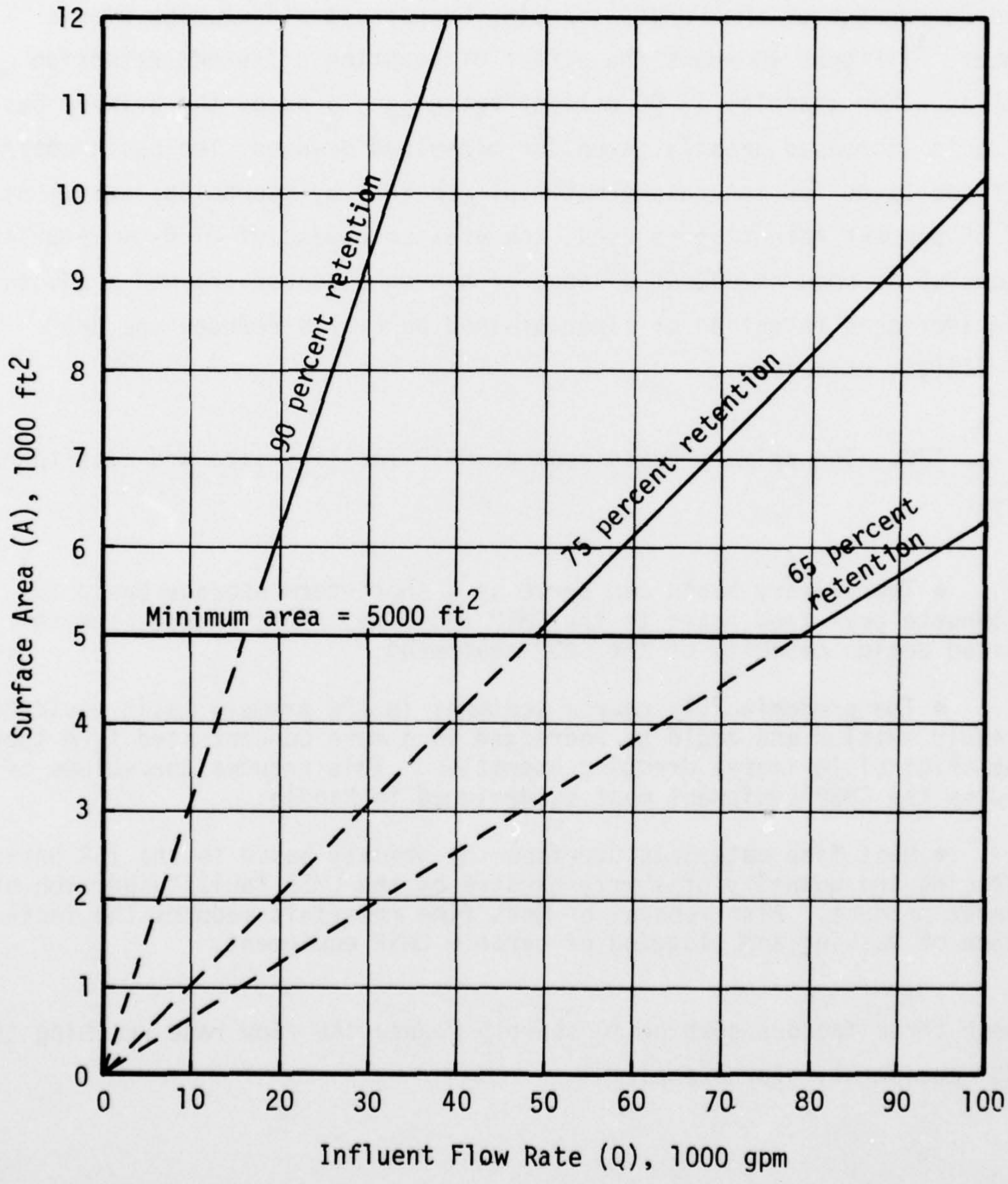

Figure 40. Primary Basin Size to Retain Various Percentages of Incoming 150-μm Material

should production of a spec product be the goal. Also, according to Table 6 and Figure 40, the ≥75 percent figure permits use of the minimum basin size for dredges up to 28 inches, which accounts for over 95 percent of the Corps- and privately-owned cutterhead and dustpan dredges[26] and 89 percent of the Corps' seagoing hopper and sidecasting dredge fleet.[34] Figure 40 shows the effect of adopting different retention values. For example, if 90 percent retention is used, the primary basin size is increased greatly, even for mid-sized dredges. The basin could get too large for convenient material recovery by mechanical equipment. If 65 percent retention is used, the greater bypass of ≥150-μm material shows up as reduced output of spec or non-spec coarse-grained products; the increased retention of finer-grained particles reduces the CMSP facility's efficiency.

177. The primary basin reduces CMSP facility size and cost three ways:

- The primary basin can serve as a short-term storage basin to attenuate peak feed rates to the CMSP facility. This reduces the required design capacity of the CMSP equipment.

- The predominantly coarse sediment in the primary basin would be freshly settled and could be redredged in a more concentrated form than the original (primary) dredging operation. This reduces the volume of slurry the CMSP equipment must be designed to handle.

- Most fine materials overflow the primary basin to the ISR basin reducing the quantity of slurry handled by the CMSP facility per ton of coarse product. Also removal of most fine materials reduces the incidence of masking and clogging of certain CMSP equipment.

These three factors combine to sharply reduce the flow rate reaching the CMSP equipment. For example:

given:	Primary dredge flow (Q)	= 16,000 gpm for 8 hours/day
	Incoming solids concentration by weight (C)	= 10%
	Solids specific gravity (SG)	= 2.65
	Gradation envelope	= Figure 11

then: From Figure 40, the primary basin area is 5000 ft^2. From Figure 8, the solids delivery rate is:

$$SDR = 0.25 \times 16{,}000/(100/10 - 1 + 1/2.65) = 427 \text{ tph}$$

The estimated percentage of all incoming material that would be retained in the primary basin is computed to be 60 percent as follows:

- Calculate the particle diameter that would be retained (according to the ideal settling theory*) using Equation 1 (see Paragraph 114) suitably revised:

$$D = (785.5 \text{ F } Q/A)^{1/2}$$

For this example, $D = (785.5 \times 1.2 \times 16{,}000/5000)^{1/2} = 55\ \mu m$.

- Using the median or weighted average gradation curve of the gradation envelope, read off the percent coarser than D. For this example, the result is about 60 percent.

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* Note that the ideal settling theory is used throughout this chapter to estimate retention and production rates. This theory holds that all particles larger than the computed size are retained in the settling basin; all smaller particles are bypassed. This contrasts with the more realistic settling theory which shows that, for a given inflow and basin area, only a fraction of the incoming particles of any size will be retained. Figure 40 was developed using this latter theory. Also, Chapter 7 uses the realistic settling theory exclusively for sizing the ISR basin, since the ISR basin plays a much more critical role in meeting effluent standards than does the primary basin and CMSP facility and thus warrants the more conservative results of the realistic theory. The ideal settling theory provides adequate accuracy for primary basin and CMSP equipment calculations; unaccounted for losses of some coarser-grained material are balanced to a large extent by unaccounted for retention of finer-grained material.

Therefore, the sedimentation rate in the primary basin is 0.6 x 427 tph = 256 tph. If the secondary dredge works continuously, its output must be 256 tph/3 = 85 tph. With a solids concentration of 20 percent solids by weight, Figure 8 shows a flow rate of

$$Q = 4 \times 85(100/20 + 1/2.65 - 1) = 1488 \text{ gpm}$$

to be sufficient. The flow rate to the CMSP facility has been reduced by a factor of 16,000/1488 = 10.7. The contributions from each of the items listed above can be estimated as follows:

- Solids budget balance factor = (Average daily on-line time by secondary dredge)/(Average daily on-line time by primary dredge). In example above, 24/8 = 3. This assumes that the solids budget is balanced on a daily basis. The District could, of course, select some other period (say a week) if the particular features of a case so lend themselves.*

- Solids concentration factor

$$= C_s[100 + C_p(1/SG - 1)]/C_p[100 + C_s(1/SG - 1)]$$

where the subscripts s and p refer to the concentrations of the secondary and primary dredge, respectively. In the example above, 20[100 + 10(1/2.65 - 1)]/10[100 + 20(1/2.65 - 1)] = 2.14.

- Solids reduction factor = 100%/(Estimated percentage of incoming material which would be retained in primary basin). For example above, 100%/60% = 1.67.

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* In some cases, another basis is necessary; for example, a large primary dredge working 24 hours/day would probably require an impracticable number of secondary dredges working full-time to keep up. A weekly or seasonal balance might be considered in this case; or a system other than a primary basin might be used.

Total factor in this example = 3 x 2.14 x 1.67 = 10.7.*

178. The above procedure requires that the primary basin have some storage capacity, which must be examined when selecting the basin's depth. In the example above, the net solids retention when the primary dredge is on-line is 142 tph = 256 tph - 114 tph (solids removal rate from Figure 8, assuming one Mud Cat dredge pumping a 20 percent slurry at 2000 gpm). If the retained material has a bulk density of 1600 g/l (964 g/l dry solids density), the net storage rate will be about 175 cyh (cubic yards per hour) which, in a 5000-ft^2 basin, fills nearly a foot of storage per hour. After 8 hours of primary dredge operation, about 7.5 feet of storage would be needed. Add an assumed 3 feet of water to ensure the Mud Cat does not become grounded and 2 feet for freeboard, and the total dike height in this example would have to be about 12.5 feet. The actual work day is important to note for operating cost computations. In the above example, the Mud Cat's pump-out rate (2000 gpm) exceeds that needed to achieve a 24-hour balance in the solids budget (1488 gpm). Thus, when the primary dredge is off-line, the solids stored over the 8-hour on-line period will be pumped out faster than necessary, in 10 hours instead of 16, resulting in 6 hours of downtime for the secondary dredge and CMSP facility.

179. Obvious problems arise when the primary dredge shuts down and the slurry in the primary basin is drawn down by a secondary dredge--as the supernatant and solids are pumped out, the secondary dredge can

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* Even if the primary dredge operates continuously, a considerable reduction factor would result from the primary basin system in this example, specifically 2.14 x 1.67 = 3.6, i.e., a secondary dredge flow of about 4450 gpm would suffice. This flow rate would, of course, require use of more than one Mud Cat-class secondary dredge (at 2000-gpm capability). The implications of using more than one secondary dredge are discussed later in this chapter.

be grounded or run out of water for slurrifying the sediment. Makeup water, either fresh or recirculated within the disposal sites, is needed to prevent these problems. We recommend that effluent from the CMSP facility be recirculated to balance the secondary dredge's pump-out rate (see Figure 41). When the primary dredge is on-line, overflow from the CMSP facility should be fed to the ISR basin with the primary basin's overflow to avoid an increase in primary basin inflow rate (hence decrease in retention of >150-μm material) and confusion about the composite gradation curve from the merging flows from the primary dredge and recirculating CMSP overflow. When the primary dredge goes off-line, the CMSP overflow is diverted to the primary basin where nearly all the particulates settle out* leaving a relatively clean supernatant.

180. Recirculation has consequences with regard to the downstream ISR facility, but constitutes neither a significant advantage nor disadvantage. These consequences stem from the cut off of all flow to the ISR facility when the primary dredge is off-line. From Figure 41, it is evident that in this example, if CMSP overflow passes on to the ISR basin regardless of whether the primary dredge is operating, the ISR basin will "see" 2000 gpm with 7.3 percent solids when the primary dredge is off-line and 16,000 gpm with 5.1 percent solids when the primary dredge is on-line. Clearly, these two influents could result in considerably different sedimentation conditions in the ISR basin. This would not be a detriment, however, if the primary function of the ISR facility is to reduce the solids concentration to some specified maximum for economical flocculation in the FSR facility. Since the ISR basin is designed to handle the "worst case" influent, the concentration reaching

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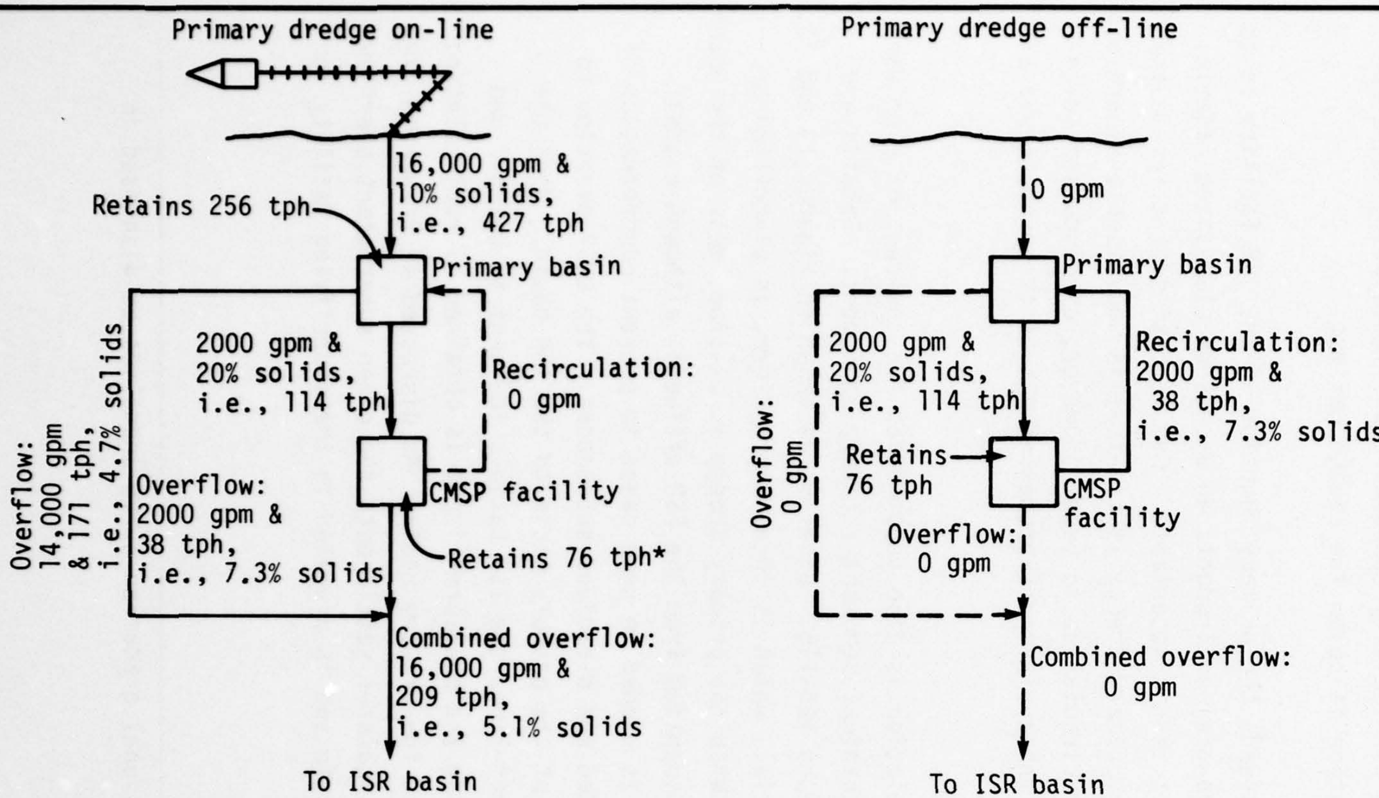
* Because of the small surface loading rate of the recirculated flow and because the particles suspended in this flow were those which had been trapped in the primary basin under the more severe settling conditions imposed by the primary dredge inflow rate.



Note: Values shown apply only to the example described in Paragraph 177.

* 144 tph x 40% (Figure 11 percentage ≥ 150 μm)/60% (percent of material retained in primary basin).

Figure 41. Slurry and Solids Flows With and Without Primary Dredge Inflow for Example With Primary Basin/Secondary Dredge

the FSR facility will never exceed the specified value.* In fact, when the "better case" influent is present, the ISR basin retains more fines than necessary; the FSR facility consumes less flocculating agent because the concentration is below the design maximum.

181. If, instead, the primary function of the ISR facility is to provide a clean fine-grained product, an excess of clay-sized material in the final product is not acceptable. Overretention of clays in the ISR basin, when the primary dredge is off-line is unavoidable regardless of whether or not recirculation is used. However, as discussed in detail in Chapter 7, these clays are processed out of the product via a "secondary basin."

182. Recirculation is also recommended for the case of a primary basin served by mechanical sediment recovery equipment. Details are provided in Paragraphs 195-196. Briefly, as shown in Figures 19 and 20, the recovered material, which is in nonslurry form, is slurrified preparatory to CMSP. When the primary dredge is on-line, most of the water for slurrifying is supplied from the FSR effluent, although a small amount of blowdown is needed in some cases to prevent concentration of undesirable suspended and dissolved substances. The CMSP overflow is directed with that of the primary basin to the ISR basin. When the primary dredge is off-line, the ISR basin's influent is cut off and water for slurrifying the nonslurry input is obtained by recirculating the CMSP overflow to the primary basin. As discussed in Paragraph 179, nearly all the particulates settle out; the clean supernatant overflows from the primary basin and is diverted to the slurrifying facility for reuse.

* Except for occasional gradation curve anomalies as discussed in Paragraphs 47-50.

Holding Basin

183. The primary advantage of a holding basin over a direct feed or primary basin system is area savings in the design of the ISR basin. For a given gradation curve and solids removal requirement, the ISR basin area varies directly with inflow rate, e.g., halving the inflow rate halves the basin area. The outflow rate from a holding basin is determined by the secondary dredge(s) operating therein; there is no direct overflow. In contrast, a direct feed system and a primary basin (by virtue of its overflow) pass the inflow rate on to the ISR basin unattenuated.*

184. At flow rates normally associated with hydraulic pipeline dredges, a holding basin generally is not cost effective. First, as far as the CMSP facility is concerned, the role of a holding basin is filled in a superior fashion by a primary basin. Second, cost analyses have shown that savings from reducing the ISR basin size do not cover added capital costs for the holding basin itself (which can be large) and associated secondary dredges, plus added O&M expenses for operating the disposal facility for much longer periods with the additional manpower for the secondary dredges.

185. At very large flow rates (say approaching 100,000 gpm**), the holding basin becomes competitive. Consider a hopper dredge pump-out operation yielding 100,000 gpm. If this is pumped into a holding

* For a primary basin served by mechanical handling equipment, inflow to the ISR basin actually is greater than that entering the primary basin because slurrification of the nonslurry input is needed for CMSP.

** A pump-out facility operating at 100,000 gpm and 10 percent solids by dry weight could empty a hopper dredge hauling 2700 cubic yards of DM (capacity of the MARKHAM, which operates out of the Buffalo District) with a bulk density of 1600 g/l and a solids SG of 2.65 in less than 50 minutes.

basin served by a secondary dredge discharging 2000 gpm, the ISR basin need only be 2000 gpm/100,000 gpm = 1/50 the size it would have to be if the pump out went to a primary basin, directly to the CMSP facility, or directly to the ISR basin (if CMSP isn't necessary). However, the 2000-gpm discharge rate of the secondary dredge in the above paragraph cannot provide a daily slurry balance because of the lengthy time (over 40 hours) to empty the holding basin after each pump-out operation. If the hopper dredge return frequency is less than 40 hours, the storage requirement of the holding basin continues to grow. If the total number of deliveries to this holding basin is few, the ultimate storage needs of the holding basin might still result in a reasonable size; however, if the number of deliveries is large, storage needs might grow to unwieldy proportions. In the above example, a 2700-cy capacity hopper dredge delivering the relatively small total of 100,000 cy would need 37 loads. If each load took 4 hours, it can be shown that slurry storage needs eventually reach nearly 812,000 cy* despite the continuous operation of the secondary dredge. This volume of slurry stored to a depth of 12 feet** would require nearly 42 acres and would take 57 days to empty at 2000 gpm.

186. Clearly, the advantage of a holding basin--area savings for the ISR basin--is lost if the holding basin itself becomes huge. The holding basin's surface area could be reduced by increasing its depth; this would require a secondary dredge with greater depth-of-dredging capability than the Mud Cat. Alternatively, the storage volume itself could be reduced by increasing the secondary dredge's discharge rate,

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* Assuming a bulking factor of 1.0 between the material in the hoppers and in the holding basin.

** Maximum dredging depth of the Mud Cat dredge is 15 feet. If 3 feet of water covers the sediment to ensure that the Mud Cat will not run aground, the maximum sediment storage depth is 12 feet.

either by adding more Mud Cat dredges or by using a single larger cutter-head or dustpan dredge. For instance, a 14-inch dredge which discharges about 7600 gpm (Table 6) would reduce peak storage needs in the above example to 580,000 cubic yards and reduce the holding basin area to 30 acres. Area savings with the ISR basin are still considerable; in this example, the basin would be only 7600 gpm/100,000 gpm = 1/13 the size it would be without a holding basin.

187. The trade-offs are presented in Table 10. The decision on which of these systems to adopt will be based on available area and on relative costs. Before a decision is made, however, the bottom-dumping option (see Figures 35 and 39) should be considered. Bottom dumping eliminates the need for an expensive diked containment area (primary or holding basin) and the ISR basin will be small to moderate in size depending on the discharge rate of the secondary dredge(s).

188. Bottom dumping is no panacea, however. Environmental factors might preclude its consideration; few moderately sized and priced secondary dredges can reach the depths that would be required*; the bottom-dump area itself can reach considerable proportions. If we assume the 100,000 cy of material being delivered in the above example has a bulking factor of 1.0 at the bottom-dump site, then a 10-foot storage depth will require an area of about 4 acres.** If this area was excavated from the shoreline so as not to protrude into the river or harbor, construction would involve excavation of well over 200,000 cy. Still, in general, botton dumping is a significantly cheaper and less area-consumptive system than one of the high-rate pump-out alternatives.

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* The MARKHAM, for instance, draws 19 feet loaded; figure another 2 feet of overdepth for safety plus 10 feet for DM storage making a total depth of 31 feet in the dump area, over twice the maximum capability of the Mud Cat dredge.

** Assuming the secondary dredge discharges continuously at 7600 gpm.

Table 10

Trade-Offs for High-Rate (≈100,000-gpm)

Hopper Dredge Pump Out

Item	Pump Out into: Primary Basin	Holding Basin w/Small Secondary Dredge Capability	Holding Basin w/Large Secondary Dredge Capability
Basins	Small (<1 acre) primary basin; large (10's of acres) ISR basin	Largest (10's of acres) holding basin; medium (≈5-acre) ISR basin	Large (10's of acres) holding basin; medium (<10-acre) ISR basin
Secondary dredges	Inexpensive Mud Cat-class dredge(s)	Inexpensive Mud Cat-class dredge	Expensive larger dredge or multiple Mud Cats
CMSP facility	Low feed rate	Low feed rate, longest operating time	High feed rate, long operating time

189. Bottom dumping is attractive even if, as is usually the case, pump-out rates are not as high as that assumed above. Hopper dredges with on-board pump-out capability do not approach 100,000 gpm. The MARKHAM, for instance, can utilize both of its 23-inch, 1000-hp pumps which, according to the footnote to Table 6, put out a combined flow of about 53,000 gpm. This flow could be handled by a 5400-ft^2 primary basin and an ISR basin probably in the 30-acre size range (depending on the gradation curve of the DM). In contrast, a bottom-dump operation would probably require less than 5 acres for both the bottom-dump area and ISR basin.

190. As a general rule, we recommend the holding basin concept be given serious consideration only when a high-rate pump-out operation or an extremely fine-grained DM results in an unacceptably large ISR basin* which could be substantially reduced in size by using a holding basin served by a low-discharge secondary dredge. Generally, a bottom-dump or primary basin facility will be preferable; most often the latter if CMSP is required because preseparation of coarser materials assists in reducing the flow rate that the CMSP equipment must be designed to handle, thereby reducing equipment costs.

<u>Secondary Dredge</u>

191. Appendix A presents a tabulated comparison of data for five models of small dredges for application in a secondary dredging operation. Besides the usual comparison of unit dredging cost, ease of transportation, and minimum downtime; the following criteria were also given consideration for this rather special application:

- Small size to allow maneuverability in a small basin (e.g., a primary basin).
- Capability to dredge in shallow water to minimize dike height.
- Maximum cutter width to reduce the number of passes.

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* See Chapter 7 for ISR basin sizing procedures.

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DEVELOPMENT OF PROCEDURES FOR SELECTING AND DESIGNING REUSABLE --ETC(U)

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192. These three items favor the IHC Hollands' "Amphidredge S-170" and National Car Rental's "Mud Cat" models. Moreover, their wide, transversely-mounted, auger-type cutterhead design is especially suitable for the dredging of recently settled sediment as is required in this application. The other dredges are equipped with standard cone-shaped cutterheads better suited to first cut dredging of compacted sediment.

193. The manufacturers of the Amphidredge S-170 were reluctant to endorse its performance in dredging anything coarser than silts or clays. Hence, its application would have to be limited to cases where the DM is in this fine range. The other model considered suitable--the Mud Cat--has additional advantages according to its manufacturer[35]:

- The cutterhead is capable of following the natural contours of the basin bottom without damage to a natural or man-made seal.

- A wheel attachment for the cutterhead is available allowing the dredge to operate in plastic- or rubber-lined basins in case such a need arises.

- Dredging can be done while moving in the forward or backward directions.

194. One notable shortcoming of the Amphidredge S-170 and Mud Cat is their relatively limited dredging depth--16.3 feet and 15 feet respectively. For primary basin or holding basin applications, this is generally no problem; but for a hopper dredge bottom-dump application, where the loaded hopper dredge itself might draft over 15 feet, this would be a factor precluding their selection--the Dixie Dredge Corporaton's CS-8E or Ellicott Machinery Corporation's Dragon Series 600 would then receive first attention. To date, applications of any of these dredges have not been extended significantly into actual secondary dredging situations. Accordingly, pilot studies should be conducted to provide a reliable basis for selection.

Mechanical Handling Systems

195. A mechanical handling system may be used in place of a secondary dredge in many applications (with the exception of a holding basin operation). The system would consist of a dragline, bucket, or dipper unit, a hopper in which to dump the material, and a conveyor to feed the material to CMSP alternative 7 or 8, which are designed to handle a nonslurry input. Figure 42, derived from Figure 35, shows delivery systems utilizing mechanical handling equipment to feed the nonslurry input to the CMSP facility. The solids input will be predominantly coarse-grained if the input is via a primary basin (which bypasses most fines) or in an "as delivered" state (with both coarse- and fine-grained material) if input is direct from the DM delivery point. Material fed into the CMSP facility is slurrified via a slush box (Figures 19 and 43) or vibrating screens with water spray (Figure 20).* The resulting slurry should be about 20 percent solids by dry weight except for the direct feed (without primary basin) case for CMSP alternative 8, which needs a slurry with about 10 percent solids.**

196. The various equipment which makes up CMSP alternatives 7 and 8 and the material feed system is sized and costed in different ways. Mechanical handling equipment is sized according to cyh handling rate; grizzlies, vibrating screens, and classifiers according to gpm input; screw classifiers according to tph product output. Thus, in designing, all these factors must be determined. The cyh figure must be selected so as to balance the solids budget (as determined by the delivery rate from the primary dredge) over some selected time span.

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* A semi-dewatered material will tend to clog No. 100 (150-μm) screens at the high input rates being used, thereby precluding coarse/fine separation in the nonslurry state.

** The additional dilution in the latter case is to prevent the high fines content from clogging the classifier in CMSP alternative 8.

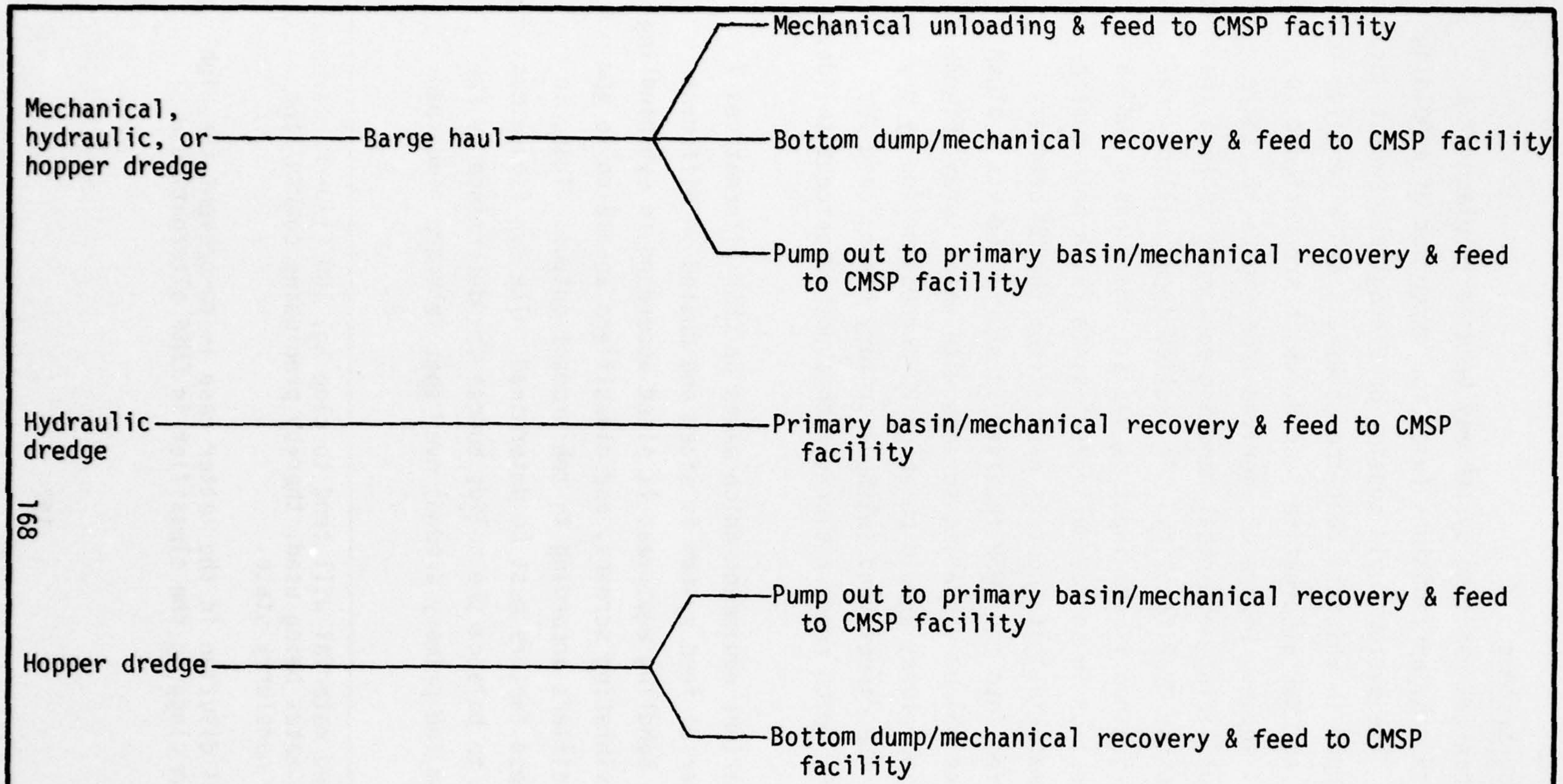
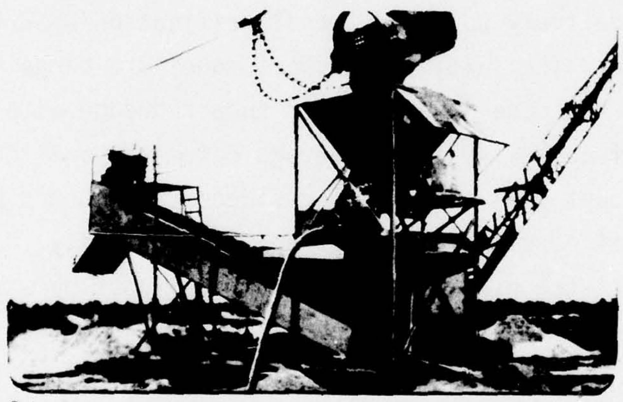


Figure 42. Delivery Systems Producing a Nonslurry Input



Relatively dry material deposited in hopper is fed to a slush box where water is added. Material in slurry state then flows to the screw classifier in CMSP alternative 7.

Courtesy of Eagle Iron Works

Figure 43. Mechanical Handling Equipment Feeding CMSP Alternative 7

Otherwise, either accumulating DM eventually will exceed the temporary storage capacity of the primary basin or bottom-dump area or so many barges will tie up waiting to be unloaded that the efficiency of the initial transport system will begin to suffer.

197. There are two distinct mechanical handling situations involving slightly different means of estimating cyh handling rate, gpm input, and tph output figures needed for design. These cases are discussed in the following two paragraphs. First, consider direct feed of DM from the delivery point to the slurrification/CMSP facility. This case applies where the initial transport mode is a barge with mechanical unloading or if the mode is a barge or hopper dredge with bottom-dump and mechanical recovery. Use the average material handling rate in cyh based on the amount delivered daily divided by the hours per day worked by the mechanical handling equipment and CMSP facility, not the primary dredge.* Convert the cyh input to tph solids input by using the bulk density.** Use the tph solids input to find the gpm input via Figure 8 with a solids concentration of 10 percent if the feed is to CMSP alternative 8, 20 percent if the feed is to alternative 7. Find the tph product output by multiplying the tph solids input by the fraction of incoming solids >150 μm per the median gradation curve.

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* For the bottom-dump case, the examples in this report assume a bulking factor of 1.0 between the material in the barge or hopper and as it settles in the bottom-dump area, a sufficiently accurate assumption. Note also that these examples assume a daily balance of the solids budget. The District could select some other period (say a week) if the particular aspects of a case so lend themselves.

** The bulk density can be estimated by dividing the weight of the delivered material (if known) by its volume. In many cases, the weight will not be known and the in situ bulk density of the DM must be used as an approximation.

Example: A primary dredge operates 8 hours per day and loads five barges, each carrying 1000 cy. The DM is delivered to a disposal site utilizing CMSP alternative 8 operating 16 hours per day. The in situ bulk density of the DM is 1600 g/l with a solids specific gravity of 2.65. Figure 11 shows the "as delivered" gradation curve. Therefore,

5 loads/working day x 1000 cy/load x working day/16 hours = 313-cy/h handling rate. From Equation 5,*

Solids density = 2.65 (1600 - 1000)/(2.65 - 1) = 964 g/l

Solids input = 313 cyh x 964 g/l x 8.425 x 10^{-4} (t/cy)/(g/l) = 254 tph.

From Figure 8 for a 10 percent solids concentration, the slurry flow rate must be 9530 gpm input. From Figure 11, 40 percent of the incoming solids >150 μm; therefore,

Coarse-grained output = 0.4 x 254 tph = 102 tph output**

198. Second, consider indirect feed of DM via a primary basin served by a mechanical recovery system. This arrangement would apply if the initial transport mode is a barge or hopper dredge with pump-out or if DM delivery is via pipeline from a hydraulic dredge. Compute the average material handling rate based on the daily delivery rate divided by the hours per day worked by the mechanical recovery equipment and CMSP facility; adjust for the primary basin's solids retention (found

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* See STEP 1 of Key to Figure 9.

** The remaining 152 tph solids is carried to the ISR basin in a somewhat diluted slurry. This slurry's flow rate is assumed to be equal to the influent flow rate by virtue of wash water, precipitation, etc. roughly offsetting water losses during the processing. Thus, the solids concentration can be found from Figure 8 given Q and the SDR. In this example, Q = 9530 gpm, SDR = 152 tph; therefore C = 6.1%.

per Paragraph 177). From the cy/h handling rate, calculate the gpm input and tph output per the example above, but with a slurry concentration of 20 percent by dry weight.

Example: A hopper dredge working 16 hours per day delivers four loads of DM, each 2700 cy. The pump-out rate is 40,000 gpm with a solids concentration of 10 percent by dry weight into a 5000-ft^2 primary basin* served by mechanical recovery equipment 24 hours per day. The in situ bulk density of the DM is 1600 g/l with a solids specific gravity of 2.65. Figure 11 shows the "as delivered" gradation curve. With this information, the particle diameter retained in the primary basin (according to the ideal settling theory) is

$$D = (785.5 \times 1.2 \times 40{,}000/5000)^{1/2} = 87\ \mu m.$$

Using the median curve in Figure 11, 52 percent of all incoming solids will be retained. The average volumetric delivery rate to the primary basin over the working day is

$$4 \text{ loads/working day} \times 2700 \text{ cy/load} \times \text{working day}/24 \text{ hours} = 450 \text{ cy/h}.$$

As shown in the previous example, a bulk density of 1600 g/l is equivalent to a solids density of 964 g/l.** Therefore,

---

* A minimum primary basin size of 5000 ft^2 is used in this report for mechanical recovery systems as well as for secondary dredge removal, even though for the former, maneuvering room is not a factor. The reasons: storage depths for the retained material can become undesirably large with a small surface area; settling conditions in a very small basin might be disrupted to an unacceptable degree by the mechanical recovery operation. However, the District could select the smaller basin if circumstances suggest that this would be advantageous.

** The in situ bulk density value is a better approximation for the indirect feed case than for the direct feed case because the coarser-grained material retained in the primary basin tends to have a higher bulk density than the in situ DM. This offsets to some extent the effect of bulking which tends to decrease bulk density.

Solids input = 450 cy/h x 964 g/l x 8.425 x 10^{-4} (t/cy)/(g/l) = 365 tph, of which 52 percent or 190 tph is retained. The resulting volumetric input rate (the design capacity of the mechanical recovery equipment) is

190 tph/[964 g/l x 8.425 x 10^{-4}(t/cy)/(g/l)] = 234-cy/h handling rate.*

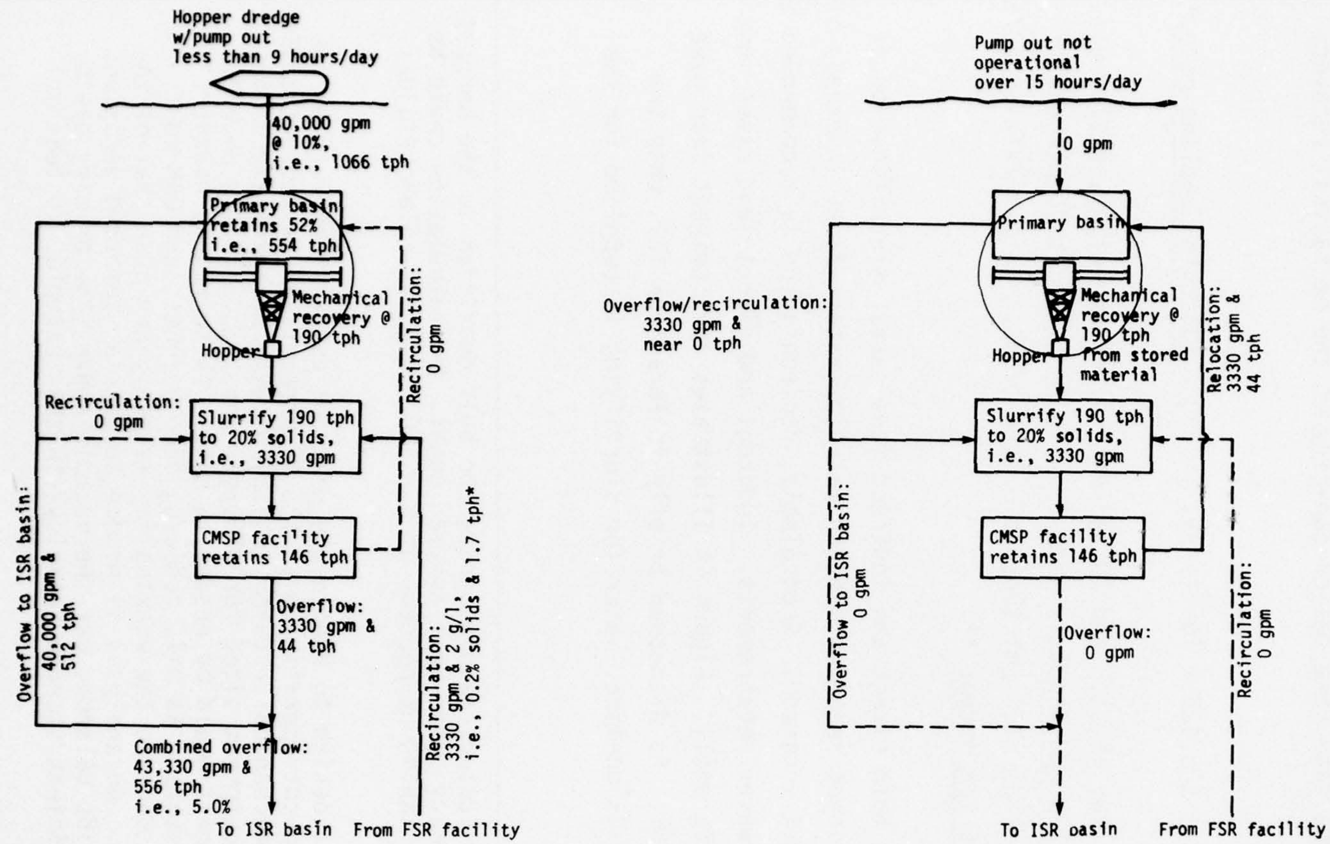
From Figure 8, for 190 tph and 20 percent solids by weight, a slurry flow rate of 3330 gpm input is needed. Figure 11 shows 40 percent of all incoming solids >150 μm; therefore, the product output rate is 40/52 x 190 tph = 146 tph output.**

199. In both direct and indirect feed cases, slurrification of the nonslurry input requires substantial flow rates--flows in excess of 3000 gpm are not uncommon. Accordingly, recirculation is recommended to reduce makeup water requirements. Indirect and direct feed cases must be treated differently. Figure 44 illustrates the indirect feed case in Paragraph 198. As discussed briefly in Paragraph 182, when the primary dredge is on-line, water for slurrifying is supplied for the

---

* In this particular example, where the bulk densities in the hoppers and in the primary basin were assumed equal, the calculation could be made simply by taking 52 percent of the 450-cyh gross volumetric delivery rate.

** Note that a design to handle the peak solids delivery rate of the 40,000-gpm pump-out operation with its 10 percent solids concentration would require mechanical recovery equipment with a capability of 682 cyh and CMSP equipment sized for 9700-gpm input and 426-tph output. Costlier equipment would be needed to handle these rates; however, primary basin storage is nil, reducing dike heights, and O&M costs might be lower because the working day is no longer than that of the primary dredge. An analysis is needed to make an informed decision. With daily solids balance, per the example above, the primary basin must have sufficient storage capacity--in this example, 15 feet of solids storage.



* Value of 2 g/l is assumed applicable effluent standard. SDR of 1.7 tph has been disregarded in computations.

Figure 44. Solids and Slurry Flows for Example of Mechanical Recovery from Primary Basin

most part from the FSR facility effluent.* Materials that can be flocculated are not concentrated with each cycle; materials not responding to the flocculating agent do concentrate, but so slowly as to generally be disregarded, particularly since the primary basin's overflow continuously dilutes the recirculated water; there is a 92 percent (40,000/43,330) turnover of water due to the large FSR effluent in the example shown. A small amount of fresh makeup water might be needed if concentrations became unacceptable. When the primary dredge is off-line, flow to the ISR basin is cut off,** but slurrification water must still be supplied. This is accomplished by recirculating the CMSP overflow to the primary basin where nearly all the particulates settle out and the clean primary basin overflow is diverted to the slurrification facility.

200. Figure 45 illustrates the water supply situation for the direct feed case of Paragraph 197. In Paragraph 197, the solids feed rate is sized to provide a daily balance of the solids budget. Therefore, the situation does not change even when the primary dredge ceases operation for the day; there is no need to cut off flow to the ISR basin. However, because there need be no outflow of water in this system, other than evaporation from the solids output stockpiles, concentrations will tend to increase much quicker than in the indirect feed case. Therefore, a continuous blowdown is desirable, with makeup water sufficient to cover both evaporative losses and the blowdown.

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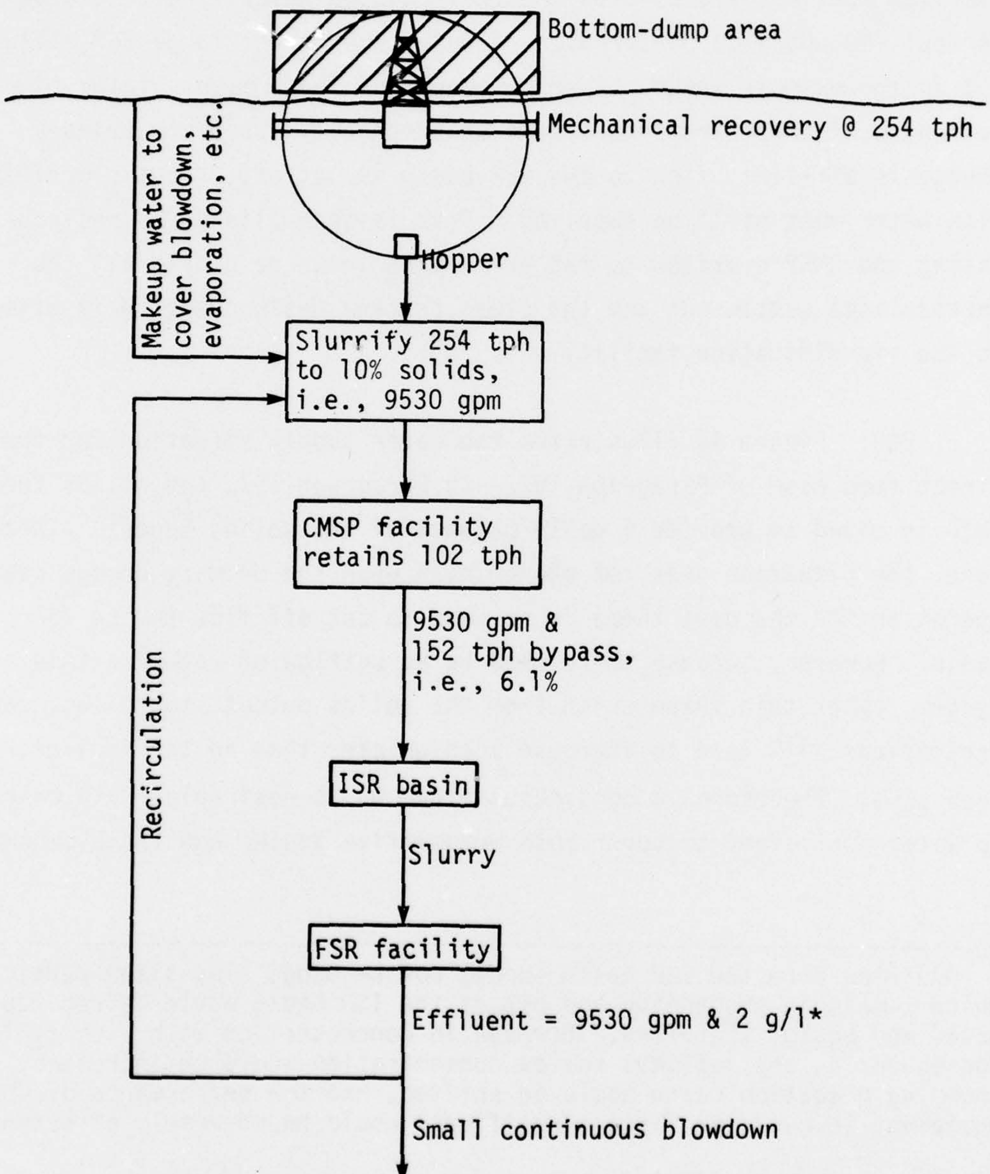
* Overflow from the ISR basin should not be used; clay-sized particles which remain in suspension and bypass the ISR basin would be recirculated and would, therefore, increase in concentration with each cycle. Consequently, the influent solids concentration would be increased, the incoming gradation curve would be shifted, and the performance of CMSP equipment (e.g., clarifiers/classifiers) would be adversely affected.

** See Paragraphs 180-182.



* Value of 2 g/l assumed applicable effluent standard.

Figure 45. Solids and Slurry Flow for Example of Mechanical Recovery Without Primary Basin

PRELIMINARY COST ESTIMATES

Inclusions and Exclusions

201. At the end of this section, capital cost curves are presented for individual pieces of CMSP equipment (Figures 47-55). In addition, for illustrative purposes, example "composite"* capital cost curves (Figures 56 and 57) and "composite" O&M cost data (Figures 58 and 59 and Table 14) are shown for the alternative CMSP facilities. These examples illustrate how relative costs for alternative CMSP facilities vary with inflow or solids delivery rate, how they compare with one another, and how the type of delivery system can influence the economic picture. In preparing actual preliminary costs, the reader assembles his own composite costs for CMSP facilities which warrant consideration using specific flow rate, solids concentration, etc., determined by the particular dredge and gradation curve for the case being studied.

202. The cost data in this section are based on current (1976) prices (except as noted) and are derived from:

- Actual installations.
- Projects from pilot studies and other literature.
- Manufacturers' information.

These costs should be used only for conceptual design and planning studies. For more refined cost estimates, detailed facility designs should be prepared and quotes obtained from equipment suppliers. (Phase V discusses these activities.) A listing of suppliers which were contacted is given in Appendix B.

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* Composite cost data represent total costs for CMSP facilities comprising the combinations of equipment shown in Figure 12.

203. In general, the composite capital costs shown include all equipment and controls necessary, plus installation, foundation work,* and equipment support steel. The costs do not cover the following except as noted:

- Freight.
- Buildings---the need and cost for housing equipment varies with climate and other local conditions and must be determined on a case-by-case basis.
- Special site conditions requiring, for example, pile foundations, rock excavation, etc.
- Pumping between processes.
- Automated control.
- Administration and engineering fees associated with site design.
- Escalation costs.

Assumptions and Examples

204. The following points discuss applicability of the preliminary cost data, assumptions and approximations involved, and certain applications where the cost data might have questionable applicability:

- Point 1--Primary basin costs and land requirements

For the basic 50-foot x 100-foot basin configuration, a cost of $12,600 is used in the composite cost curves.** Larger primary basins add about $1000/1000 ft^2 of additional area (see Paragraph 176 for a discussion of primary basin area requirements).

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* Foundation costs assume excavation and backfill in good soil on a level site.

** Based on an assumed dike cross section 10 feet high with 10-foot top width; inner and outer sideslopes of 1V on 1H and 1V on 2H respectively; a cost of $3 per cubic yard in place; and land costs of $2000 per acre. See Chapter 7 for more detail on basin costs.

• Point 2--Holding basin and high-rate pump-out costs
Due to limited applicability, external high-rate pump-out facilities for hopper dredges were not costed in this report. On-board pump-out systems are more prevalent than external units; and flow rates from on-board units can generally be handled with a primary basin and ISR basin of moderate size or, alternatively, an even less expensive, less area-consumptive bottom-dump facility. Costs for holding basins may be estimated using basin costing data in Chapter 7.

• Point 3--Costing via inflow rate and solids output
Screw classifiers, the Derrick system, slush boxes, and mechanical handling equipment are sized and costed according to their respective solids output rate in tph or cyh. All other CMSP equipment is sized and costed according to the inflow rate in gpm. The solids production rate must be known or estimated from the solids content of the influent slurry (if any) and the fraction of these incoming solids which corresponds to the desired output of the equipment.

• Point 4--Secondary dredge
The possible applications of secondary dredges in delivering DM to the CMSP facility are shown in Figures 34 and 35 and Table 11. Two delivery options are illustrated in the example composite cost curves for alternatives 1-6, 9, and 10. Direct feed to the CMSP facility from a primary or secondary dredge; and indirect feed to the CMSP facility via a primary basin served by one or two secondary dredge(s).

For illustrative purposes, the composite costs are plotted against a variable input rate. These cost curves can be applied to any of the primary basin/secondary dredge applications shown in Table 11 with appropriate adjustments.* Table 12 shows the values of importance in designing and costing screw classifiers and the Derrick system using the median gradation curve in Figure 11 and the parameters in the example of Paragraph 177 (an ongoing example used throughout this report).

Figure 46 shows the cases covered in Table 12 and the composite cost curves. Note that based on the assumptions in the ongoing example, a primary basin influent rate much in excess of 23,000 gpm will require

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* For influent flow rates above 49,000 gpm the primary basin size is no longer constant (see Figure 40). With a bottom-dump facility, the CMSP facility would see a secondary dredge slurry with 20 percent solids concentration by dry weight and an "as delivered" gradation curve. With a holding basin, the solids concentration of the secondary dredge's slurry would average that of the pump-out operation (assumed to be about 10 percent) and the gradation curve would be "as delivered" to the holding basin by the hopper dredge. Bottom-dump area and holding basin costs would have to be substituted for the primary basin cost if either of these two options is selected.

Table 11

Possible Applications of Secondary Dredges in Delivering Dredged Material to the CMSP Facility

If Primary Dredge-Initial Transport Mode is:	Then Possible Application of Secondary Dredge is in:
Pipeline dredge/direct pipeline	Primary basin
Hopper dredge, pipeline dredge, or mechanical dredge/barge pump out	Primary basin
Hopper dredge, pipeline dredge, or mechanical dredge/barge bottom dump	Bottom-dump area
Hopper dredge/bottom dump	Bottom-dump area
Hopper dredge/pump out	Holding basin or primary basin

Table 12

Solids Production Rates for

Example Composite Cost Curves

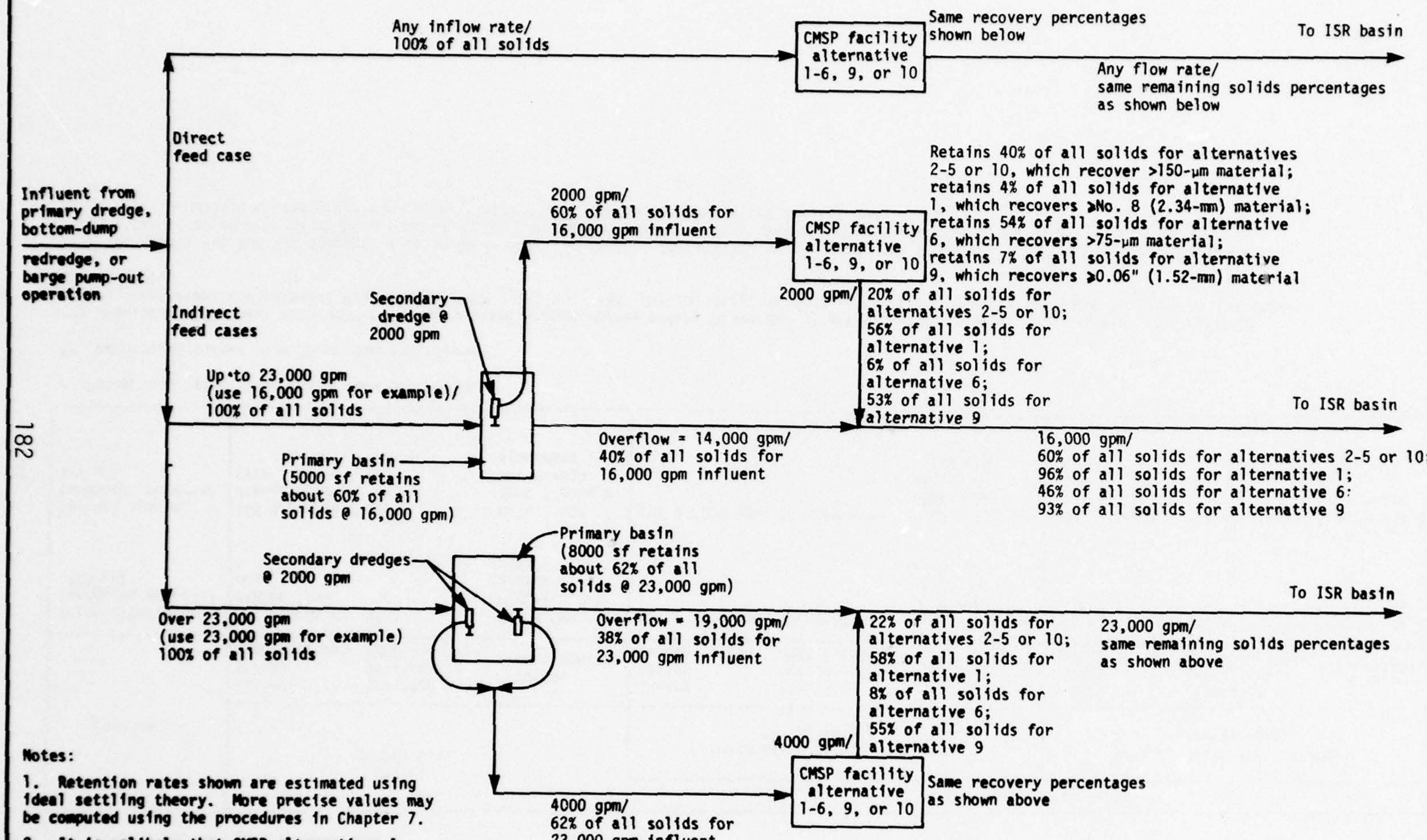
Equipment	Direct Inflow Case			Indirect Inflow Cases					
				Primary Basin/Single Secondary Dredge Case			Primary Basin/Two Secondary Dredges Case		
	Slurry Solids Concentration	Fraction Retained in CMSP Facility	Solids Production, tph	Slurry Solids Concentration	Fraction Retained in CMSP Facility	Solids Production, tph	Slurry Solids Concentration	Fraction Retained in CMSP Facility	Solids Production, tph
Screw classifier (produces material >150 μm)	10% @ primary dredge flow rate	40%*	0.4 x SDR from Figure 8 for dredge flow rate	20% @ 2000 gpm	40/60=67%***	0.67 x 117 tph (SDR from Figure 8) = 78 tph	20% @ 4000 gpm	40/62=65%****	0.65 x 234 tph = 152 tph
Derrick system (produces material >75 μm)	10% @ primary dredge flow rate	54%**	0.54 x SDR from Figure 8 for dredge flow rate	20% @ 2000 gpm	54/60=90%***	0.90 x 117 tph (SDR from Figure 8) = 105 tph	20% @ 4000 gpm	54/62=87%****	0.87 x 234 tph = 204 tph

* Percentage larger than 150 μm read off Figure 11.

** Percentage larger than 75 μm read off Figure 11.

*** Paragraph 177 shows this 5000-ft^2 primary basin retains approximately 60 percent of all incoming solids in this example. The retained solids then become the material fed into the CMSP facility. The CMSP facility, in turn, retains the fraction of these incoming solids shown in the table.

**** To handle two Mud Cat dredges, a basin 80 feet by 100 feet is the minimum size. Using the procedure in Paragraph 177, this basin retains particles down to 53 μm for a flow of 23,000 gpm (the breakpoint in this particular example where two secondary dredges become necessary). According to the gradation curve, Figure 11, 62 percent of the solids are retained.



Notes:

1. Retention rates shown are estimated using ideal settling theory. More precise values may be computed using the procedures in Chapter 7.

2. It is unlikely that CMSP alternatives 1 or 9 would actually be used in this example because of the very low recovery rates (4 and 7% of all incoming solids, respectively).

Figure 46. Delivery/Processing Options for Example Composite Curves

a secondary dredge capability of over 2000 gpm.* In this situation, the primary basin must be served by (and accordingly sized to accommodate) two Mud Cat dredges or one dredge of different make with adequate discharge.

• Point 5--Mechanical handling and secondary dredge costs
Preliminary costs for mechanical handling systems cover draglines only. Other bucket- and dipper-type equipment was not costed in this report. The composite cost curves shown assume use of Mud Cat secondary dredges at $100,000 each, including accessories. Costs for other secondary dredges are shown in Appendix A.

• Point 6--Clarifiers and classifiers
Preliminary costs for clarifiers/classifiers do not include a supplemental water system for high silt content situations (see Paragraph 159).

• Point 7--Conveyors
Conveyor selection depends on such factors as characteristics of the material to be conveyed, desired capacity, multistack capability, etc. Some systems even provide for continuous weighing and recording of material flow, an advantageous feature for facilities selling DM-derived products. Clearly, conveying and stockpiling equipment must be selected for the specific application. Accordingly, detailed cost estimates of conveyor systems were not made; a figure of 10 percent of the cost of the other CMSP equipment was used to cover conveyor costs.

• Point 8--Cyclones
A preliminary cost figure of $8 per gpm for cyclones with capacities >1000 gpm was used. This cost includes all pipes, valves, gauges, pump, and support structure, but excludes installation.

• Point 9--Miscellaneous Costs
In cases where equipment prices supplied by manufacturers did not cover supporting braces, frames, or structure and foundation costs, a figure of 30 percent of the cost of the particular piece of equipment was used. Equipment installation costs to cover consulting and supervision by manufacturer representatives were estimated at 20 percent of the equipment cost.

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* This can be calculated using the procedures discussed in Paragraph 177. It can also be shown that a secondary dredge discharge of over 2000 gpm would be needed should the primary dredge flow rate remain at 16,000 gpm (the value adopted for the ongoing example), but the primary dredge operates over 11 hours per day, instead of 8 as assumed in Paragraph 177.

•Point 10--Interpretation of Figure 56 composite costs

Figure 56 shows example composite capital cost curves for CMSP alternatives 1-6, 9, and 10, which handle a slurry input. Three delivery conditions are shown: direct feed to the CMSP facility from the primary dredge, bottom-dump area, or barge pump out; indirect feed via a primary basin served by a single Mud Cat dredge; and indirect feed via a primary basin served by two Mud Cat dredges. In an actual design situation, the District would have a specific primary dredge (hence, flow rate) in mind and a specific DM-derived product (hence, no more than four CMSP alternatives) to consider; design and cost analyses would be far less complex than Figure 56 seems to suggest.

The striking difference in slope between direct and indirect feed curves is due to differences in sensitivity to the delivery flow rate. In the direct feed case, CMSP equipment must be sized to handle the delivery flow rate; costs for each piece of equipment go up roughly in proportion to the delivery rate as shown in Figures 47-51. Conversely, in the indirect feed case, CMSP equipment is sized and costed for the fixed flow rate (and, in the case of the screw classifier and the Derrick system, a fixed solids delivery, hence, output rate) from the secondary dredge(s); the flow rate into the primary basin has no impact (other than determining whether there must be one or two secondary dredges). Similarly, the cost of the primary basin/secondary dredge(s) is constant over the flow range plotted.

The composite cost curves in Figure 56 (with the exception of those for alternative 6) may be applied with reasonable accuracy to most costing situations involving alternatives 1-6, 9, and 10. The only component whose cost varies significantly with, for instance, a change in gradation curve, would be the screw classifier, which represents only a small part of the total cost. Alternative 6, the Derrick system, is the exception. Its costs are largely on the basis of product output (in tph) which is highly sensititve to gradation curve changes.

CMSP alternative No. 9 (see Figure 12) is highlighted in Figure 56 as an example. For primary dredge (or bottom-dump redredge or barge pump-out) flow rates up to about 15,000 gpm, the direct feed system provides the cheapest CMSP/material feed system (in terms of capital costs); from 15,000 to 23,000 gpm, the primary basin/single secondary dredge is cheapest. Above 23,000 gpm two Mud Cat-class dredges would be needed to serve the primary basin in this example. As a result, the direct feed system again is cheapest, although there is a large step increase in costs at this point. Above about 30,000 gpm, the primary basin/two secondary dredge system becomes the cheapest alternative. Of course, capital costs are not the sole factor to evaluate in selecting the CMSP alternative and material feed system; O&M costs are equally important.

•Point 11--Interpretation of Figure 57 composite costs

Figure 57 shows the composite capital cost of installed equipment for CMSP alternatives 7 and 8, facilities designed to handle nonslurry

input. These alternatives produce two distinct DM-derived coarse products--separated/washed (alternative 7) and separated/classified/ washed (alternative 8).

In Figure 57, the broken lines present costs for the indirect feed (with primary basin) case; the solid lines present costs for the direct feed (without primary basin) case. Costs for alternatives 7 and 8 are related to primary dredge output; but unlike alternatives 1-6, 9, and 10, the primary dredge output is not the single most important factor. Rather, costs are dependent on the mechanical handling rate, which in turn is a function of primary dredge output per work day and the hours per work day of the CMSP facility (see the discussion in Paragraphs 195-200).

For alternative 7, the indirect feed (broken line) cost curve is higher than the direct feed (solid line) cost curve because the former includes the cost of the primary basin. For alternative 8, the relative direct and indirect feed costs depend on the specific situation. The added cost for a primary basin in the indirect feed case is offset to some extent because a smaller classifier is adequate to handle the more concentrated slurry (i.e., less slurry is needed per ton of coarse material).

Figure 57 could be adjusted easily to extend its applicability to other DM delivery cases. The direct feed costs shown cover the barge mechanical unloading case; these costs could be modified to cover instead a barge or hopper dredge bottom-dump case by including the costs for a bottom-dump area. However, unlike Figure 56, Figure 57 is too case-specific to be of general applicability. The results are quite sensitive to assumed values for bulk density, relative working hours, gradation curve, etc., shown on the figure. The reader should examine Figure 57 only in the context of an illustrative example. The multiple abscissae, (mechanical handling rate, cyh; reslurrification flow rate, gpm; and product output, tph) may be used to check the costs of individual component equipment if desired.

- Point 12--Permanent versus mobile equipment

The preliminary costs presented in this report for CMSP and material handling equipment assume permanent installation. In many instances, however, an individual disposal site may be operative only a week, a month, or some other fraction of the time. In these cases, permanent installation makes poor economic sense; portable equipment should receive serious consideration. The equipment could be transported from site to site trailing the District's primary dredge as the latter makes its scheduled rounds.

Operation and Maintenance Costs

205. Operation and maintenance (O&M) costs for CMSP facilities and associated DM feed systems are presented in this report on a per

diem basis assuming 24-hour-per-day operation. If the work day is other than 24 hours, the per diem costs can be adjusted proportionately. The District can readily estimate the annual O&M costs for each disposal site based on the projected number of days of operation during the dredging season. Daily costs comprise:

- Operating costs (labor and supervision).
- Utility costs (fuel and electricity).
- Maintenance costs (labor and material).

These items are discussed in the following paragraphs. Note that as explained in Paragraph 138, for reasons of simplicity of presentation, replacement costs are not included. In effect, the useful life of the various pieces of equipment is assumed to equal that of the disposal site itself.

206. Operating costs were based on salary scales for similar workers in industry. Current (1976) rates, including normal payroll burdens, but less overhead and profit,* were estimated to be $11/hour. Supervisory services were not allocated specifically to the CMSP facility; these services must be provided for the disposal site as a whole from DM delivery to CMSP to ISR and FSR. Table 13 shows the estimated manpower needs for the ten CMSP alternatives and two indirect delivery systems (mechanical handling and secondary dredge).

207. Utility costs cover fuel and electricity. Equipment consuming significant amounts of electricity includes: vibrating screens, circular thickeners, hydrocyclones, screw classifiers, and the Derrick system. Utility costs for hydrasieves, grizzlies, and classifiers/

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* This assumes District-operated facilities. If operation of the disposal facility is contracted out to private industry, overhead and profit factors should be included.

Table 13

Manpower Requirements for

CMSP Facility

Position	CMSP Alternative 1	2	3	4	5	6	7	8	9	10	Mechanical Handling System	Secondary Dredge
Supervisor	0	0	0	0	0	0	0	0	0	0	0	0
Operator	0	3	3	3	0.5	2	0	3	0	0.5	3	3
Laborer:												
Low to medium flows	0	1.5	1.5	1.5	0	0	0	1.5	0	0	3	3
High flows	0	3	3	3	0	0	0	3	0	0	3	3
Totals:												
Low to medium flows	0	4.5	4.5	4.5	0.5	2	0	4.5	0	0.5	6	6
High flows	0	6	6	6	0.5	2	0	6	0	0.5	6	6

Notes:

- Units are equivalent 8-hour shifts per 24-hour working day.
- Alternatives 1, 7, and 9 require no specific commitment of manhours; occasional attention by workers assigned elsewhere in the disposal facility is adequate.
- These figures do not include manpower requirements for rehandling stockpiled coarse materials.
- Flows refer to primary dredge flows for alternatives 1-6, 9, and 10; reslurrification flows for alternatives 7 and 8. Low to medium flows are in the ≈20,000-gpm range; high flows are >30,000 gpm. Manpower needs for flows between these values might be based on the >30,000-gpm figure for conservative planning.

clarifiers were assumed negligible. Utility costs for conveyors were not included. Electrical costs were computed at an assumed rate of \$0.035/kilowatt hour.

208. Daily fuel costs for a secondary dredge were estimated to be \$62.40 based on a consumption rate of 6.5 gallons per hour,[35] an assumed unit cost of \$0.40 per gallon, and a 24-hour work day. Daily fuel expenses for a mechanical handling system were estimated in a similar fashion to be \$72 for equipment handling up to 200 cyh and \$156 for equipment capable of handling in excess of 200 cyh.[36]

209. Maintenance costs (labor and materials) were estimated to be about 10 percent of the installed capital cost of equipment per year. This value was adopted on the basis of discussions with equipment manufacturers. Converted to a daily cost, a value of 0.04 percent of the capital cost was used.

210. Table 14 summarizes O&M costs for CMSP alternatives 1-6, 9, and 10 and their associated material handling systems. Two delivery cases are shown: direct feed from the primary dredge (see also Figure 58) and indirect feed via secondary dredge(s). This table has fairly broad applicability as a costing tool for these alternatives because of the relative insensitivity of O&M costs to changes in bulk density or gradation curve.* Similarly, Table 15 and Figure 59, which show O&M costs for alternatives 7 and 8, also have general applicability in costing these alternatives. (This recommendation despite the earlier warning against using the composite capital cost curves in Figure 58 as a general costing tool. Why? Because variations in electrical and maintenance cost figures due to adjustments in CMSP equipment capability

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* Of course, applicability in any specific case depends on the particulars. For instance, this table would not accurately represent costs if a secondary dredge with substantially different first cost and flow rate is selected.

Table 14

Daily Operating and Maintenance Costs for

CMSP Facility with Direct or Secondary Dredge Feed

Material Feed System	O&M Item	CMSP Alternative 1	2	3	4	5	6	9	10
Direct feed, 2000 gpm	Labor	$ 0	$396	$ 396	$ 396	$ 44	$ 176	$ 0	$ 44
	Fuel	0	0	0	0	0	0	0	0
	Electricity	23	29	29	29	70	42	19	66
	Maintenance	6	19	25	16	22	21	9	24
	Total	29	444	450	441	136	239	28	134
Direct feed, 16,000 gpm	Labor	0	396	396	396	44	176	0	44
	Fuel	0	0	0	0	0	0	0	0
	Electricity	168	193	193	193	512	302	134	479
	Maintenance	26	88	98	56	130	91	57	162
	Total	194	677	687	645	686	569	191	685
Direct feed, 32,000 gpm	Labor	0	528	528	528	44	176	0	44
	Fuel	0	0	0	0	0	0	0	0
	Electricity	328	376	376	376	1021	588	260	954
	Maintenance	48	170	191	104	256	178	111	320
	Total	376	1074	1095	1008	1321	942	371	1318
Indirect feed, one secondary dredge, 2000 gpm	Labor	528	924	924	924	572	704	528	572
	Fuel	62	62	62	62	62	62	62	62
	Electricity	24	40	40	40	80	45	21	76
	Maintenance	52	69	75	66	71	83	56	74
	Total	666	1095	1101	1092	785	894	667	784
Indirect feed, two secondary dredges, 4000 gpm	Labor	1056	1452	1452	1452	1100	1232	1056	1100
	Fuel	125	125	125	125	125	125	125	125
	Electricity	48	77	77	77	155	88	41	149
	Maintenance	96	125	132	118	133	156	105	140
	Total	1325	1779	1786	1772	1513	1601	1327	1514

Table 15

Daily Operating and Maintenance Costs for CMSP Facility with Nonslurry Feed

Material Handling Rate, cy/h	O&M Item	CMSP Alternative 7 Direct Feed	CMSP Alternative 7 Indirect Feed	CMSP Alternative 8 Direct Feed	CMSP Alternative 8 Indirect Feed
100	Labor	$528	$528	$ 924	$ 924
	Fuel	72	72	72	72
	Electricity	21	26	46	40
	Maintenance	54	60	70	69
	Total	675	686	1116	1105
200	Labor	528	528	924	924
	Fuel	72	72	72	72
	Electricity	34	42	84	67
	Maintenance	91	98	116	108
	Total	725	740	1196	1171
300	Labor	528	528	924	924
	Fuel	156	156	156	156
	Electricity	50	59	113	84
	Maintenance	128	135	162	147
	Total	862	878	1355	1311

in response to changes in gradation curve, bulk density, primary dredge slurry solids concentration, etc., are small compared to the labor costs (see Table 13) which do not vary in response to these changes.)

Specific Example

211. For an example of comparative costing of CMSP alternatives, assume the following:

Primary dredge (Q)	= 16,000 gpm operating 2 shifts (16 hours) per day
(C)	= 10 percent solids by dry weight
Secondary dredge (if any) (Q)	= 2000 gpm
(C)	= 20 percent solids by dry weight
Gradation curve	= Figure 11 median curve
Solids specific gravity (SG)	= 2.65
In situ and primary basin bulk densities (B)	= 1600 g/l
Desired product	= Washed, unclassified coarse material (>150 μm)
Solids budget	= Balanced on daily basis

212. According to Table 9, consider CMSP alternatives 2, 4, 5, 7, and 10. Alternative 7 is the only mechanical handling case; it requires a primary basin to settle out the incoming slurry. The other alternatives have the option of indirect or direct material feed, i.e., with or without a primary basin served by a secondary dredge.

213. Direct feed of the 16,000-gpm, 10 percent slurry to the CMSP equipment yields a solids delivery rate of 427 tph (from Figure 8). The gradation curve shows 40 percent of all incoming solids >150 μm; thus, the production rate of desired material is 171 tph = 0.4 x 427 tph. Production occurs only during the 16-hour period the primary dredge is

operating; there is an 8-hour downtime each day. Thus, daily O&M costs for the CMSP (Figure 58) should be adjusted by a factor of (24-8)/24.

214. For indirect feed via secondary dredge, Figure 40 indicates that a 5000-ft^2 primary basin is adequate. Computing the required secondary dredge flow rate per the procedure in Paragraph 177:

- Time factor = 24/16 = 1.5

- Solids concentration factor = 20[100 + 10(1/2.65 - 1)]/10[100 + 20(1/2.65 - 1)] = 2.14

- Solids reduction factor--Diameter of smallest particle retained $D = (785.5 \times 1.2 \times 16{,}000/5000)^{1/2} = 55\ \mu m$. Thus, according to the gradation curve, 60 percent of all incoming material is retained. The solids reduction factor is 1.67 = 100%/60%.

The total reduction factor is 1.5 x 2.14 x 1.67 = 5.36. Therefore, the required secondary dredge flow rate is 16,000 gpm/5.36 = 2985 gpm; i.e., two Mud Cat dredges (4000 gpm total capability) or a single larger dredge are needed. For this example, assume two Mud Cats are used.

215. With two Mud Cats, however, an 8000-ft^2 primary basin is recommended for maneuvering room. Thus, the retention characteristics of the basin change as follows:

$$D = (785.5 \times 1.2 \times 16{,}000/8000)^{1/2} = 43\ \mu m$$

From Figure 11, 64 percent of all incoming material is trapped, i.e., the solids reduction factor becomes 1.56 = 100%/64%. The total reduction factor is 1.5 x 2.14 x 1.56 = 5.01; the required secondary dredge flow rate capability is 16,000 gpm/5.01 = 3200 gpm--two Mud Cats are adequate.

216. The primary basin's dike height is determined as follows: the solids retention rate in the primary basin is 273 tph = 0.64 x 427 tph. The net storage rate is 45 tph = 273 tph - 228 tph (removal rate

from Figure 8 given 4000 gpm at 20 percent solids). For a bulk density of 1600 g/l (964 g/l solids density), this is equivalent to 55 cyh = 45 tph/[964 g/l x 8.425 x 10^{-4} (t/cy)/(g/l)] which, in an 8000-ft^2 basin, occupies 0.3 feet per hour. Thus, 10-foot dikes will accommodate 16 hours of primary dredge operation, 3 feet of depth for Mud Cat operation, and 2 feet of freeboard.

217. Because the 4000-gpm capacity of the two Mud Cats exceeds the 3200 gpm required, the material in the primary basin will be removed faster than needed for a daily balance of the solids budget. The solids accumulated while the primary dredge is on-line (720 tons = 45 tph x 16 hours) will be removed in little more than 3 hours after the primary dredge stops operation, leaving nearly 5 hours of downtime. Daily O&M costs for the CMSP (Table 14) should therefore be adjusted by a factor of (24-5)/24.

218. For alternative 7, the mechanical recovery rate from the primary basin is found as follows: the total solids delivery rate to the primary basin is 427 tph. Of this, 60 percent (256 tph) is retained in the 5000-ft^2 primary basin and will be mechanically recovered at the reduced rate of 171 tph because the CMSP facility will operate 24 hours per day, whereas the primary dredge operates only 16 hours per day. The 1600 g/l bulk density (964 g/l solids density) yields a volumetric recovery rate of 211 cy/h = 171 tph/[964 g/l x 8.425 x 10^{-4} (t/cy)/(g/l)]. This value is used to cost the mechanical handling equipment and slush box. The output rate of washed coarse material will be 114 tph = 40% (incoming material >150 μm)/60% x 171 tph. This value is used to cost the screw classifier. The CMSP equipment is costed for a 3000-gpm flow rate (from Figure 8 given 171 tph and 20 percent solids).*

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* Note: This specific example of computing the costs for alternative 7 cannot utilize the composite cost curves in Figure 57 because the primary dredge's hours worked and hence daily output differ; thus, the mechanical handling rate is different.

219. Capital and O&M costs for these alternatives are shown in Table 16. The most economical system is alternative 4--direct feed, which would cost $38,900 per annum. For this investment, the District will produce about 164,000 tons of the desired material per year. Thus, the cost of the product will be $0.237 per ton. This figure does not cover costs for the primary dredge, the ISR and FSR facilities, stockpile areas, off-site egress and delivery, etc.

Table 16

Capital and O&M Costs for Specific Example

Cost Item	CMSP Alternative/Material Feed System								
	2		4		5		7	10	
	Direct feed from primary dredges	Primary basin with two secondary dredges	Direct feed from primary dredge	Primary basin with two secondary dredges	Direct feed from primary dredge	Primary basin with two secondary dredges	Primary basin with mechanical recovery	Direct feed from primary dredge	Primary basin with two secondary dredges
1. Composite capital cost*	$212,000	$313,000	$139,000	$296,000	$325,000	$333,000	$220,000	$404,000	$349,000
2. Annual cost for interest and amortization of capital cost**	20,000	29,500	13,100	27,900	30,700	31,400	20,800	38,100	32,900
3. Daily O&M cost***	451	1,408	430	1,403	457	1,198	745	457	1,199
4. Annual O&M cost****	27,100	84,500	25,800	84,200	27,400	71,900	44,700	27,400	71,900
5. Total annual cost (Items 2 + 4)	47,100	114,000	38,900	112,100	58,100	103,300	65,500	65,500	104,800

* All composite capital costs from Figure 56, with the exception of alternative 7 which is developed from its individual components.

** Assuming a 20-year life at 7 percent interest (factor 0.0944).

*** Values for alternatives 2, 4, 5, and 10 for the case of a primary basin with two secondary dredges are based on a 19-hour work day; therefore, values shown are 19/24 of those in Table 13. Values for the direct feed case are based on a 16-hour work day; therefore, values shown are 16/24 of those in Figure 58. For alternative 7, values are based on a 24-hour work day (see Figure 59).

**** Based on a 60-day work year.

All annual values rounded to nearest $100.

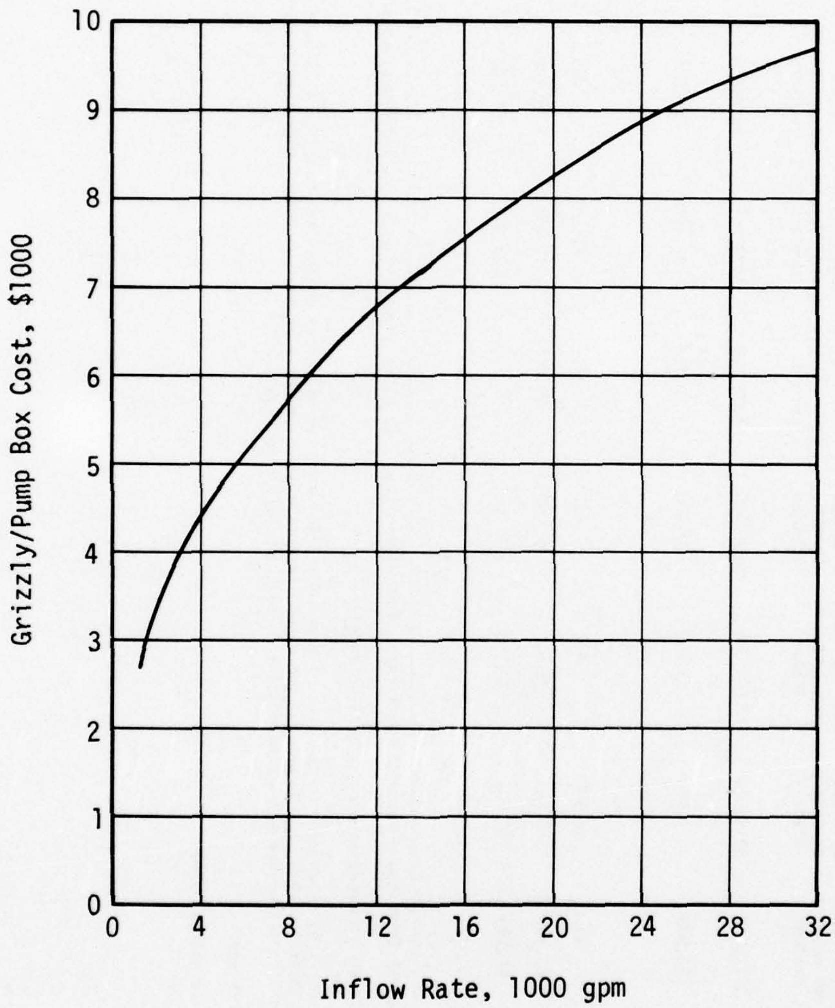
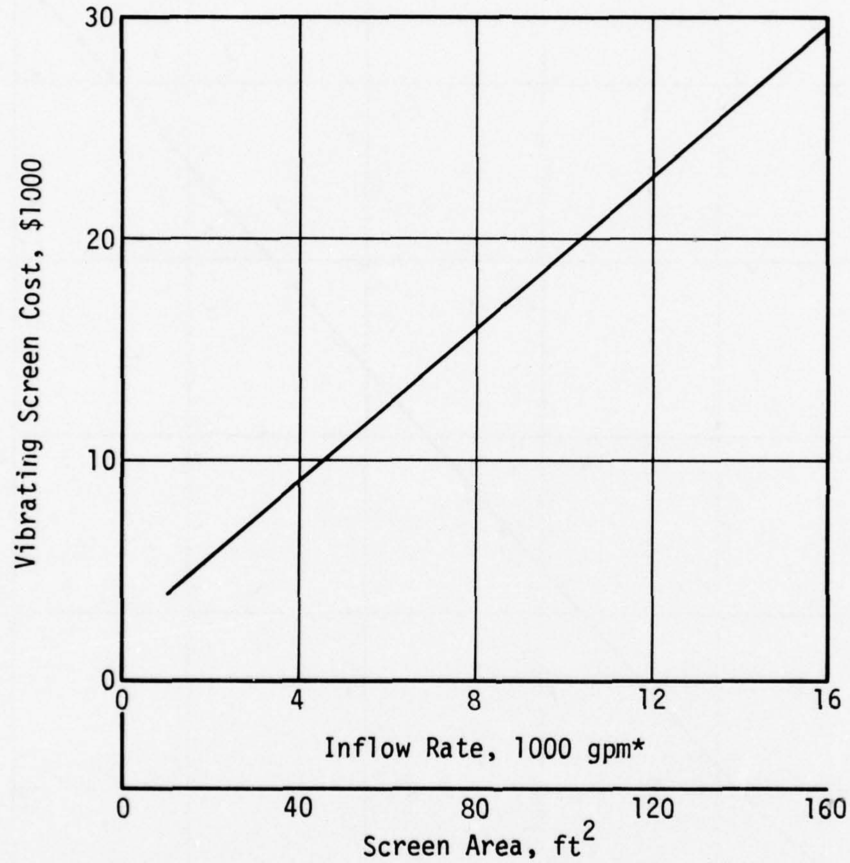


Figure 47. CMSP Equipment Costs--
Grizzly/Pump Box

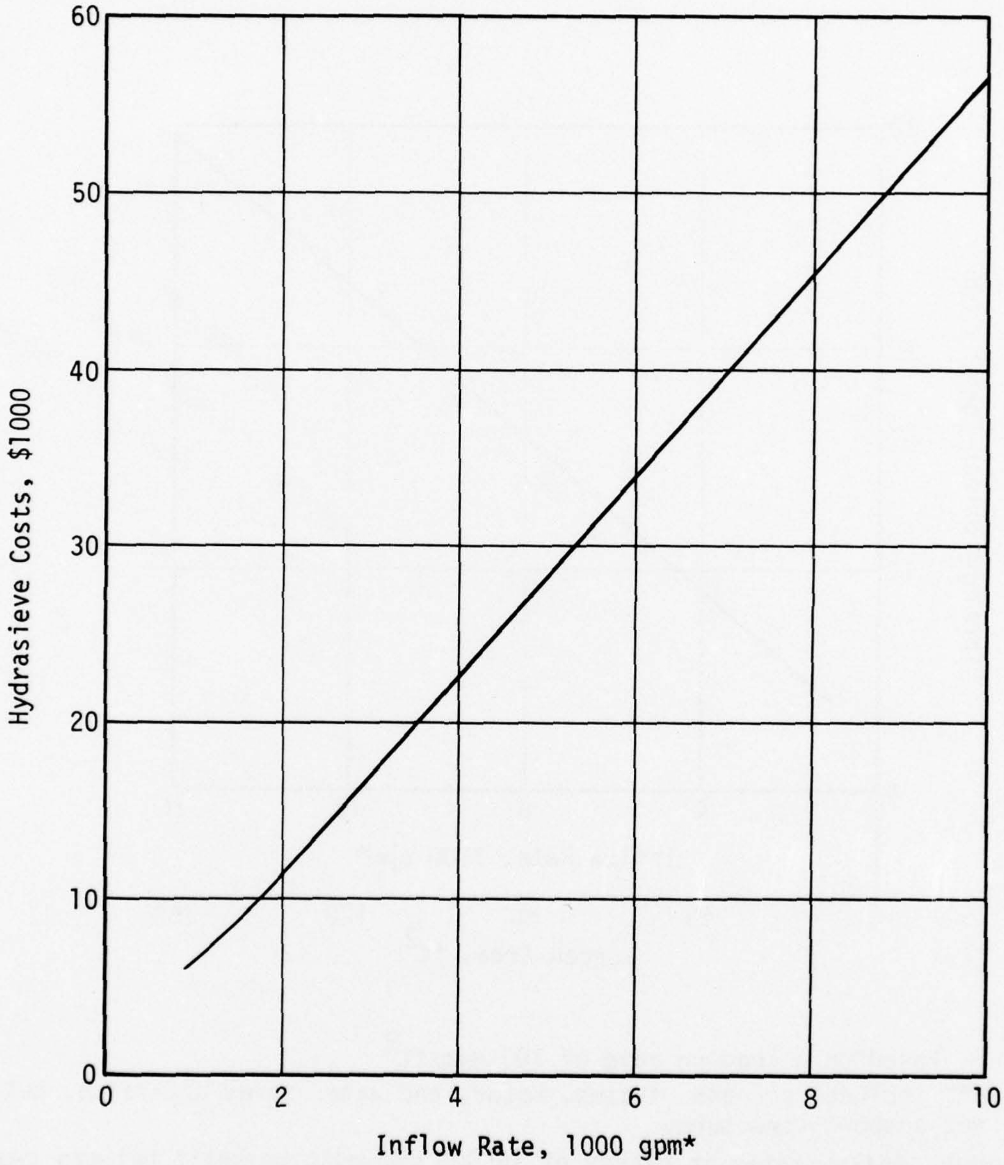


* Based on a loading rate of 100 gpm/ft^2

** Includes screens, frames, motor, and water spray apparatus, but not support structure.

Note: Inflow rates in excess of 16,000 gpm must be split between two or more units, each costed in accordance with this figure.

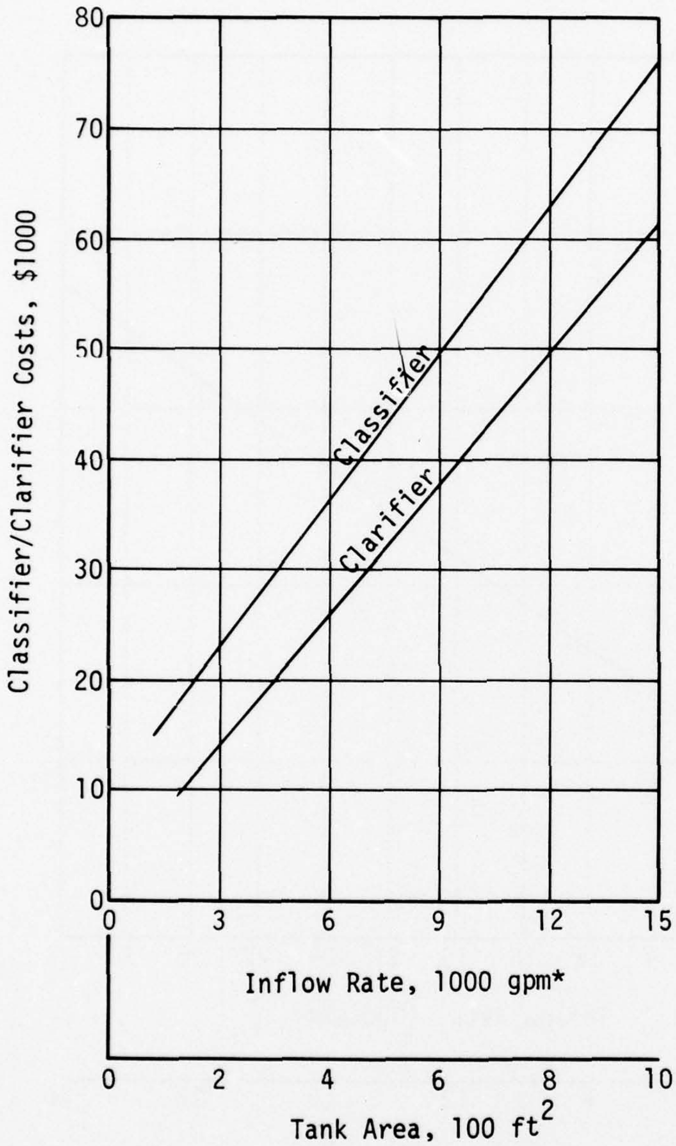
Figure 48. CMSP Equipment Costs--Triple Deck Vibrating Screens



* Based on a loading rate of 10,000 gpm for a 72-inch-wide hydrasieve. Other hydrasieve sizes will handle proportional inflow rates.

Note: Inflow rates in excess of 10,000 gpm must be split between two or more units, each costed in accordance with this figure.

Figure 49. CMSP Equipment Costs--
Hydrasieves

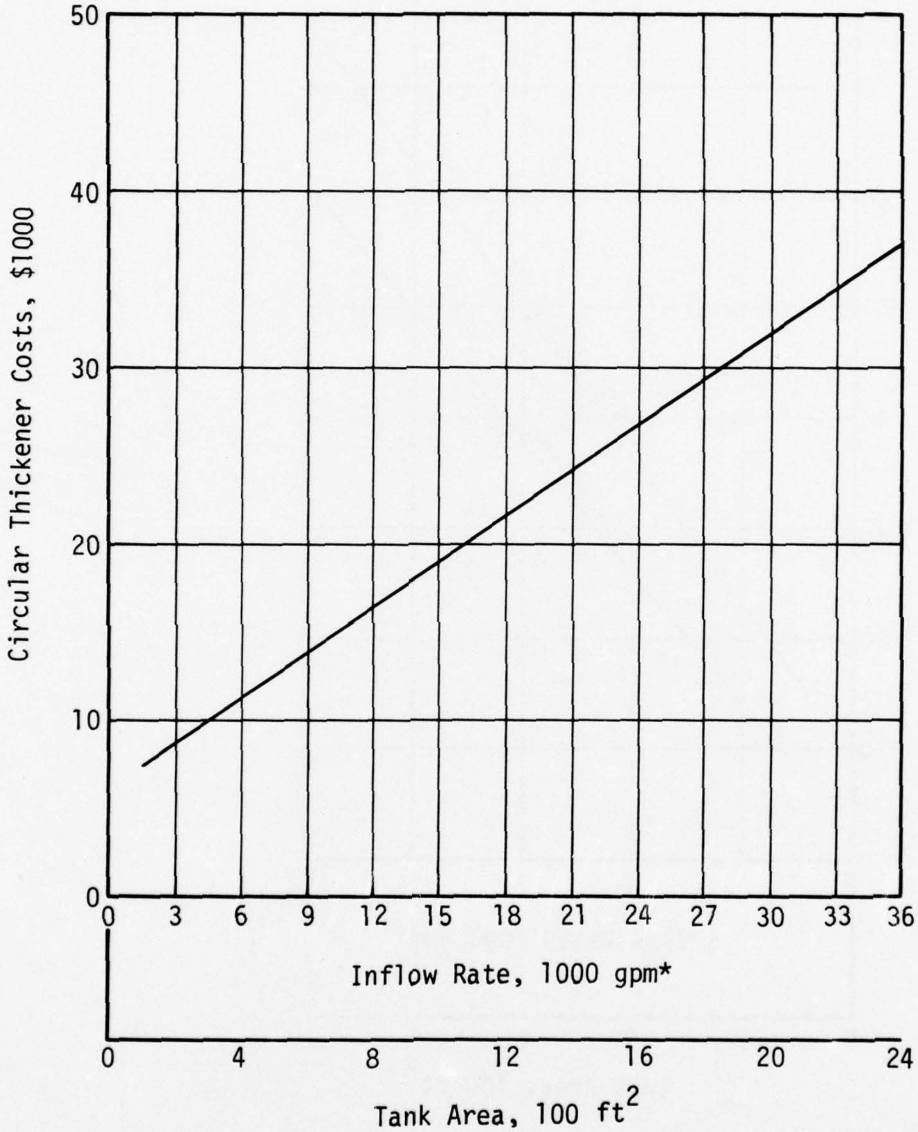


* Based on a surface loading rate of 15 gpm/ft^2 (actually retains 70-80 percent of >150-μm particles).

Note: Costs are for low silt content in slurry.

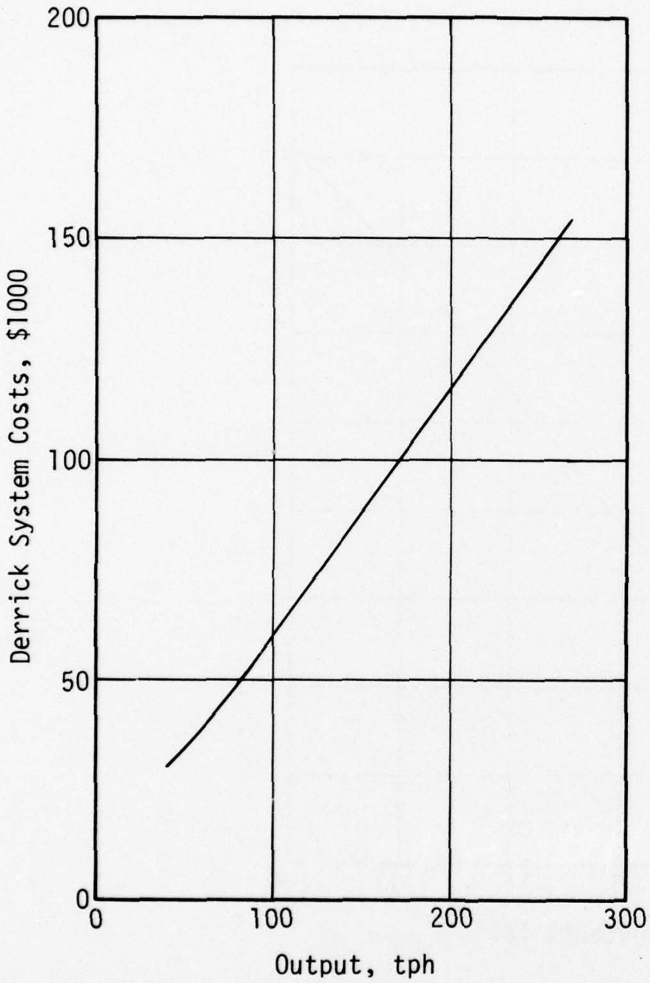
Note: Inflow rates above 15,000 gpm must be split between two or more units, each costed in accordance with this figure.

Figure 50. CMSP Equipment Costs--Classifiers/Clarifiers



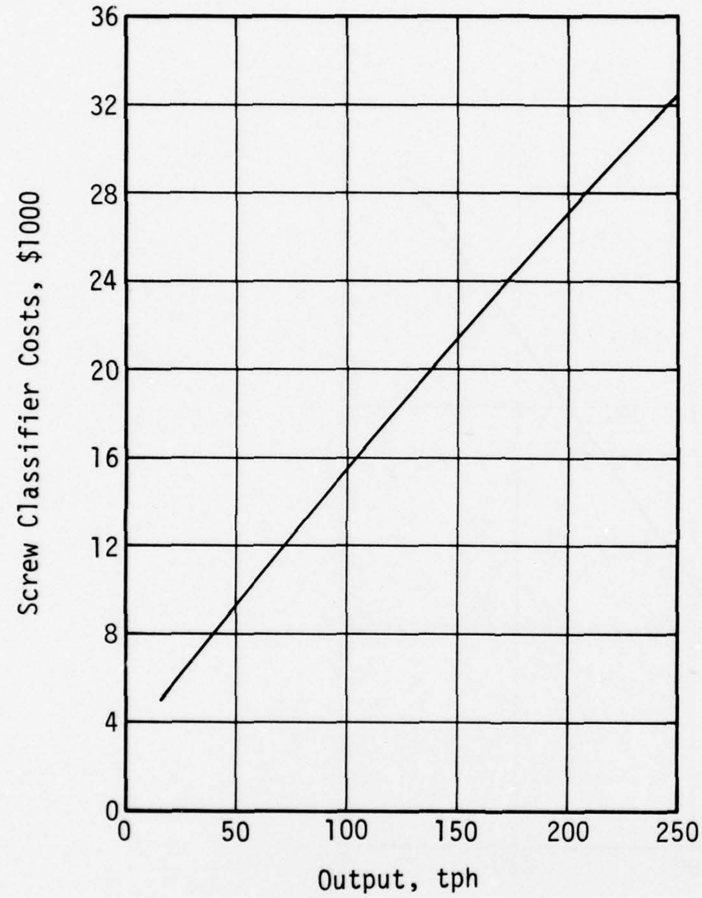
* Based on a surface loading rate of 15 gpm/ft^2 (actually retains 70-80% of >150-μm particles).

Figure 51. CMSP Equipment Costs--
Circular Thickeners



Note: Costs shown cover system and supporting structure.

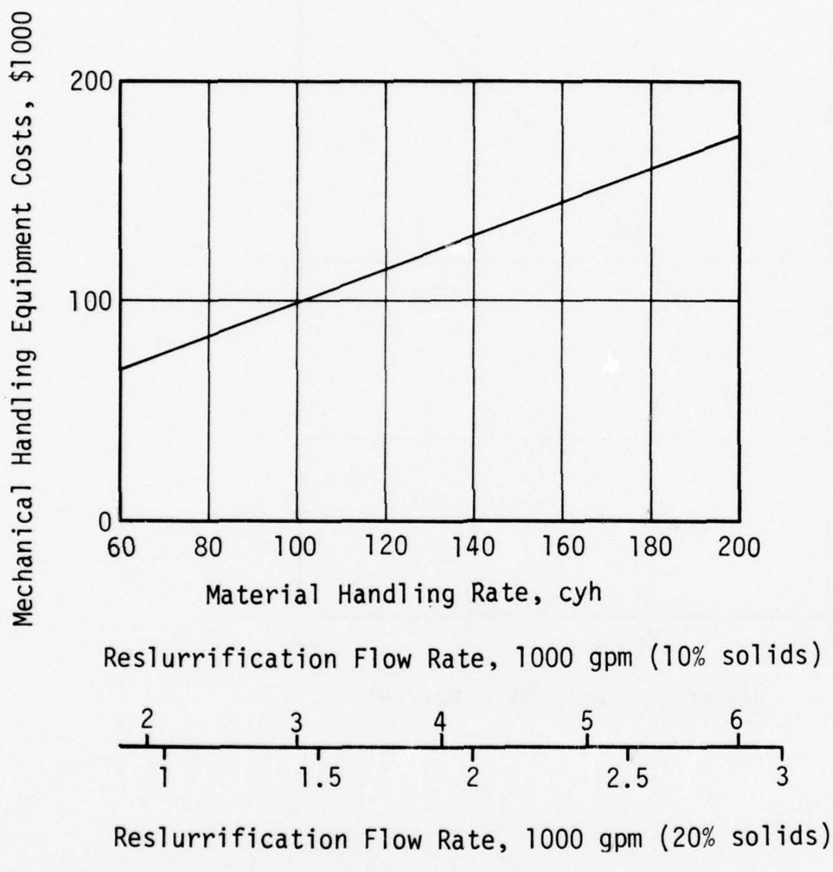
Figure 52. CMSP Equipment Costs--
Derrick System



Note: Capacities based on medium sand (10% <No. 100 mesh).

Note: Output rates in excess of 250 tph must be split between two or more units, each costed in accordance with this figure.

Figure 53. CMSP Equipment Costs--
Screw Classifiers



Note: Costs include dragline and receiving hopper.

Note: Reslurrification figures assume a material bulk density of 1600 g/l.

Figure 54. CMSP Equipment Costs--Mechanical Handling Equipment

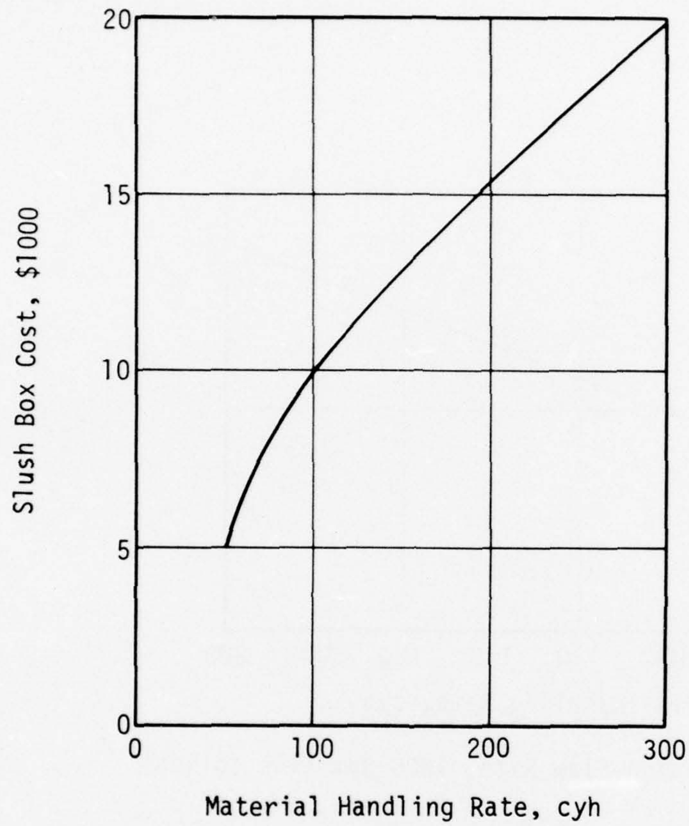


Figure 55. CMSP Equipment Costs--
Slush Box

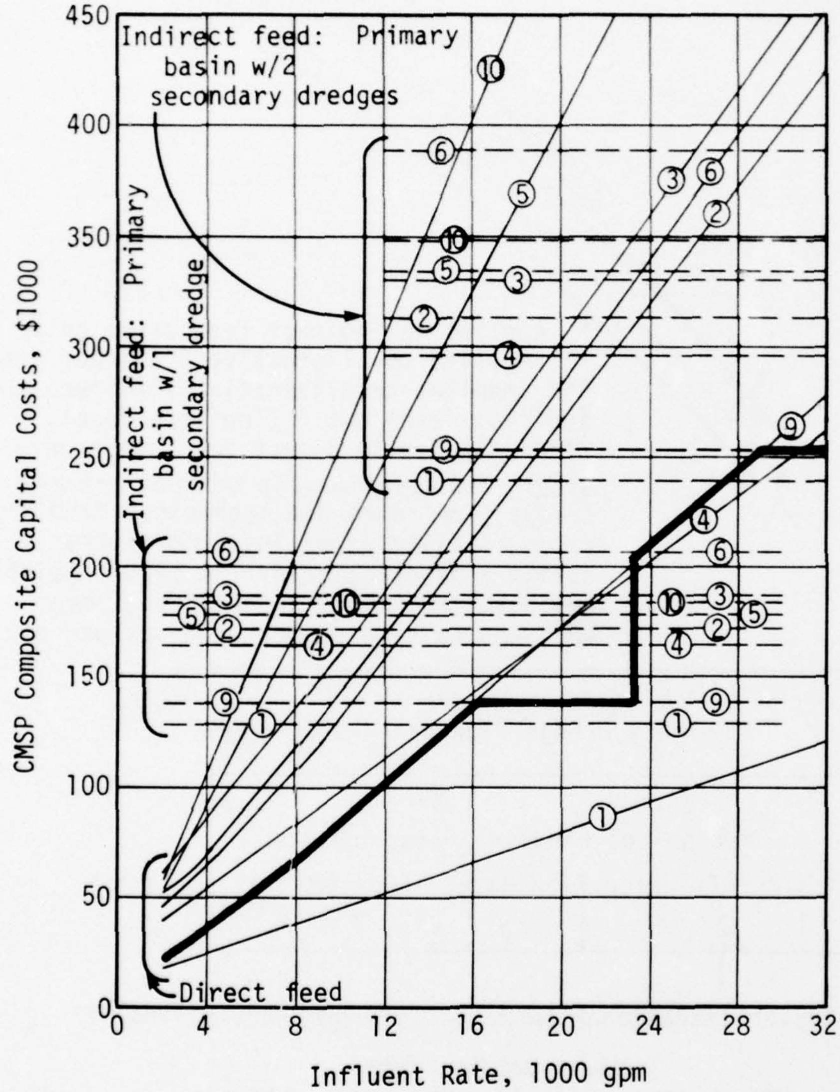


Figure 56. CMSP Facility Composite Costs--
Capital Costs for Alternatives
1-6, 9, and 10

Note: Figures shown assume a bulk density of 1600 g/l and the median gradation curve in Figure 11.

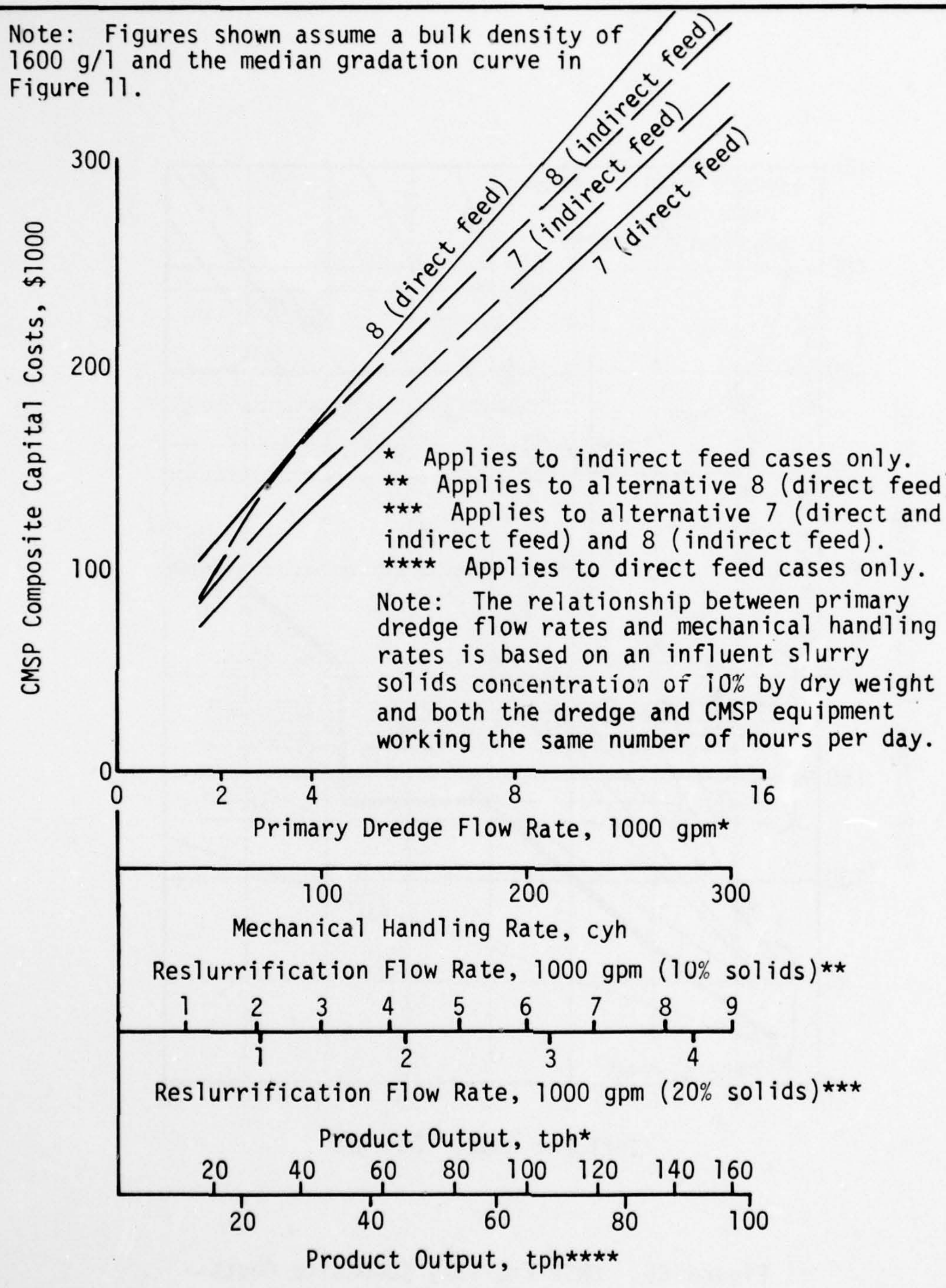


Figure 57. CMSP Facility Composite Costs--
Capital Costs for Alternatives 7 and 8

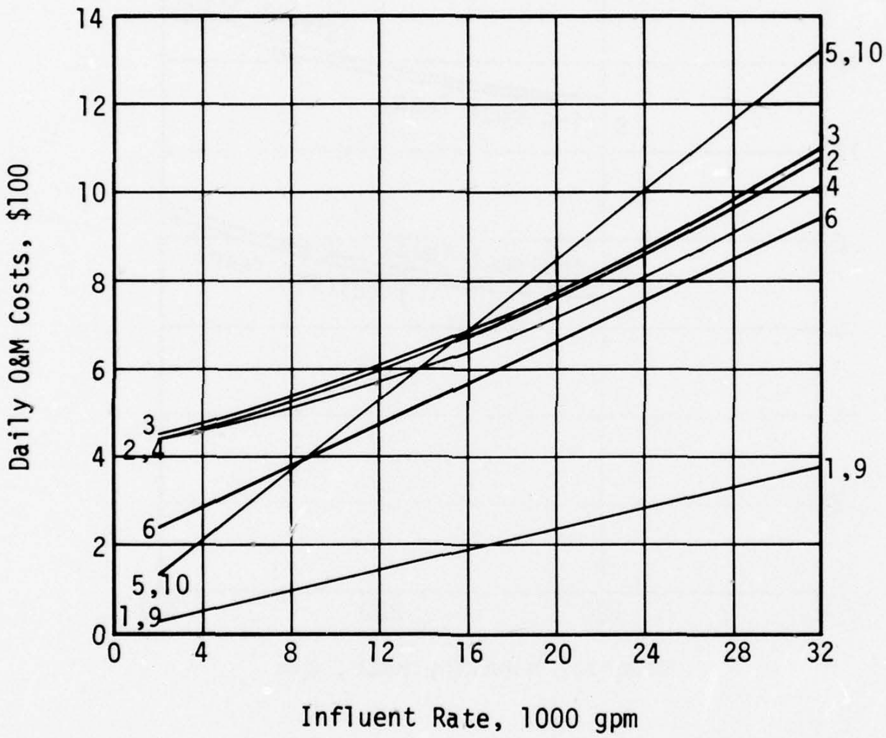


Figure 58. CMSP Facility Composite Costs--
Daily O&M Costs With Direct Feed
to Alternatives 1-6, 9, and 10

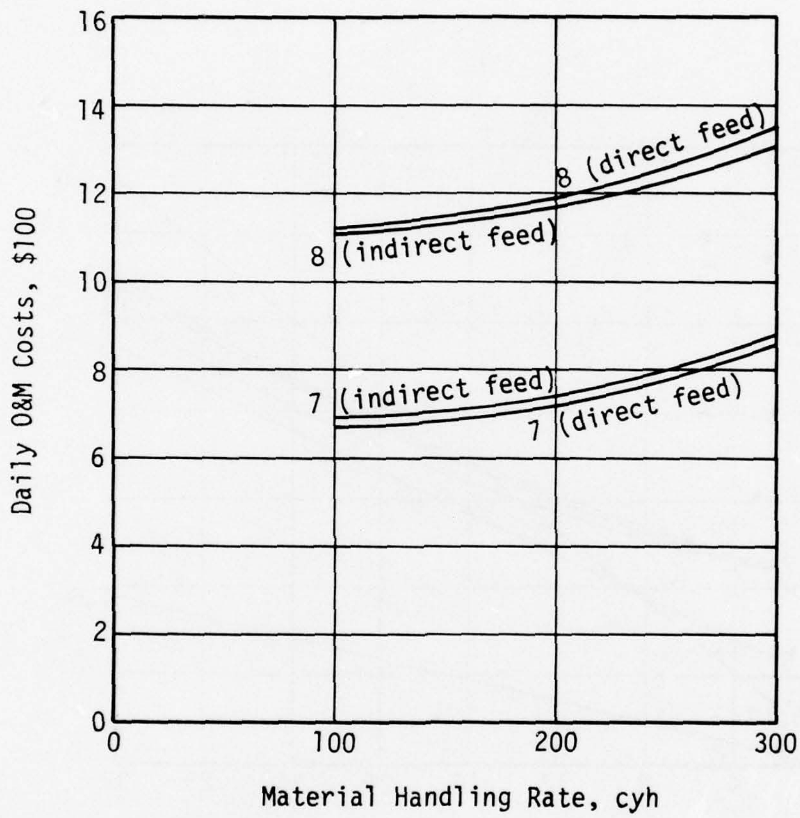


Figure 59. CMSP Facility Composite Costs--
Daily O&M Costs for
Alternatives 7 and 8

CHAPTER 7

PHASE III

FINE MATERIAL RECOVERY

DELIVERY SYSTEMS/SLURRY VERSUS NONSLURRY INPUT

220. This chapter discusses the Initial Solids Removal (ISR) and Final Solids Removal (FSR) facilities needed to remove enough suspended material from a slurry to ensure an acceptable effluent and, where sufficient demand exists, to produce a fine- or mixed- (coarse- and fine-) grained product. There are two general material feed cases:

- Slurry bypassing a CMSP facility--This covers situations where a coarse- and/or fine-grained product is desired; a CMSP facility is needed for coarse/fine separation.

- DM in slurry or nonslurry form which has not passed through a CMSP facility--This case is typified by the non-reusable disposal site, but also applies to a reusable site where a mixed (coarse- and fine-grained) material is to be utilized and/or disposed of as waste.

221. Figure 60 shows the delivery chain--primary dredge, initial transport, unloading and feed systems--between the dredging location and disposal site; the state of the DM input when it reaches the ISR facility is also shown. Facilities handling a nonslurry input are not addressed in detail in this report because of their rather straightforward, fairly standard designs:

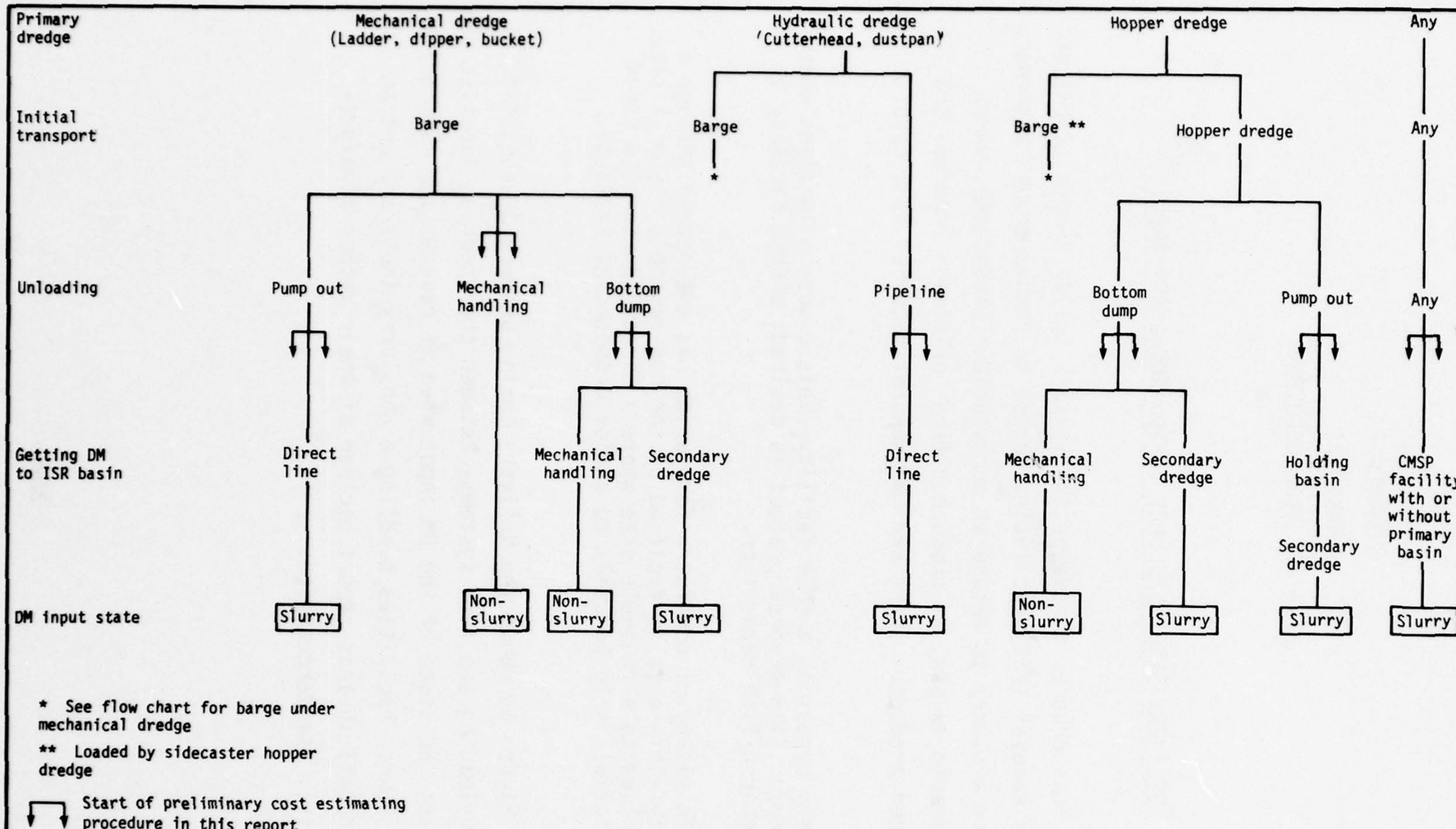


Figure 60. Dredged Material Movement from Primary Dredges to ISR Basin

- For dewatered DM in a stackable form, a stockpile area will suffice for non-reusable or reusable disposal sites. The latter, of course, will probably have provisions for loading and egress-off-site transport to get the material to a market/user and/or waste disposal area. A disposal site handling DM containing contaminants might need a low dike, circumscribing ditch, or subsurface drain system to intercept polluted runoff and drainage for subsequent treatment.

- For a partially dewatered DM of sludge consistency, a diked containment area is necessary for both non-reusable and reusable disposal sites. A runoff and leachate collection and treatment system is provided if needed. DM densification techniques* may be used to enhance dewatering/consolidation. A reusable site includes provisions for loading and egress-off-site transport of the material, probably after it has been dewatered to a stackable state.

INITIAL SOLIDS REMOVAL FACILITY--CONCEPT

222. DM reaching the ISR facility in a slurry form requires a more complex processing system. As shown in Table 7, removal of sufficient suspended material from the slurry to meet applicable effluent standards may be done on a single- or two-stage basis. A single-stage

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* Discussed in Paragraphs 273-279.

facility relies on natural, unassisted sedimentation* to do the job. Consequently, this type of facility:

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* Flocculation in a single-stage facility is economically uncompetitive with the two-stage facility. The high solids concentrations in the single-stage facility require large feed rates of expensive flocculating agents. In contrast, the low solids concentrations entering the FSR facility of a two-stage system permit low feed rates of inexpensive flocculating agents. Example:

Single-stage facility

Given:	Slurry flow rate (Q)	= 16,000 gpm for 24 hours/day
	Slurry solids concentration (C)	= 10% by dry weight
	Solids specific gravity (SG)	= 2.65
	In situ bulk density (B)	= 1600 g/l (964 g/l solids density)

Then: At this concentration, the addition of 4 percent (by dry weight) of calcium oxide will provide satisfactory flocculation, but at a cost of $80/1000 m^3 (cubic metres) of slurry.[24] Daily and unit flocculation costs are computed as follows:

$7000/day = $80/1000 m^3 x 16,000 gpm x 86,800 sec/day x m^3/35.32 cf x cfs/448.83 gpm

From Figure 8, the delivery rate of in situ solids is 427 tph, i.e.,

12,600 cyd (cubic yards/day) = 427 tph x 24 hours/day/ [964 g/l x 8.425 x 10^{-4}(t/cy)/g/l)]

Thus, the unit cost for flocculation is $0.56/cy of in situ DM = ($7000/day)/(12,600 cyd of in situ DM).

Two-stage facility

Using an ISR facility, reduce the solids concentration of the slurry entering the FSR facility to 20 g/l. With the above assumptions and using the fine-grained boundary of the gradation envelope in Figure 11, this requires a basin of less than 8 acres. With this reduced solids concentration, tests have shown that 8 mg/l of Purifloc C-31 will produce satisfactory flocculation at a cost of only $5/1000 m^3 of slurry.[24] Daily and unit costs for flocculation computed as before are $436/day and $0.035/cy of in situ DM.

- Is feasible only when the colloidal fraction is minute or the effluent standards are lenient.

- Generally requires a very large settling basin.

A two-stage facility uses natural sedimentation in the ISR facility to remove most of the noncolloidal particulates, then uses flocculation in the FSR facility to remove whatever portion of the colloidal and remaining noncolloidal suspended matter is necessary to meet the effluent standard.

223. This report focuses on the two-stage facility because:

- DM gradation, in most cases, is so fine as to require two-stage treatment. Based on sixty samples of DM from across the country, colloidal material (assumed in this report to be particles ≤ 2 μm in diameter) ranged from 4-58 percent of the sample, averaging 27 percent.[24,*]

- In single-stage removal, the "ISR" facility** can be designed using the procedures presented for the two-stage facility with appropriate parameter adjustments (e.g., its effluent must meet the applicable standards for discharge directly into the receiving body rather than some intermediate solids concentration preparatory to FSR).

224. Figure 61 is a schematic of the two-stage solids removal scheme showing the ISR facility options. The ISR facility generally is much larger than the FSR facility because the ISR basin and secondary basin (if any) rely on natural sedimentation to remove fairly fine-grained suspended particles. The ISR facility serves one of three possible functions:

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* The referenced sampling program used dispersed analyses. Thus, the percentage of colloidal particles is exaggerated over the "as delivered" gradation. Still, the predominance of large colloidal fractions in DM is illustrated by these results.

** "ISR" is a misnomer in the single-stage case since there is no second stage.

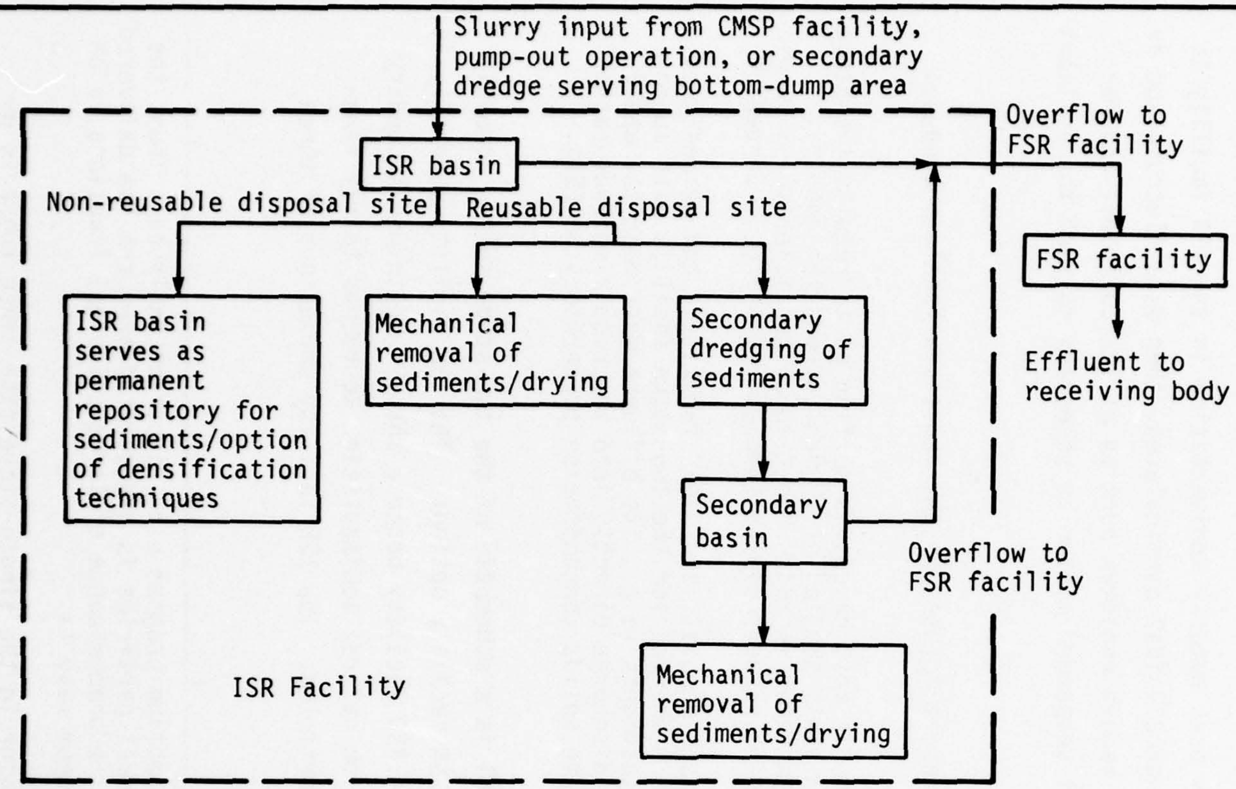

Figure 61. Two-Stage Solids Removal System--ISR Facility Options

• In a non-reusable disposal site, the ISR basin reduces the slurry's solids concentration for economical flocculation in the FSR facility; it also serves as a permanent repository for the sediment.*

• In a reusable site, the usual ISR facility function is to provide a suitable influent for economical flocculation; a less common function is to produce a specified clean, fine-grained product.**

225. Recovery of sediment from the ISR facility eventually must be by mechanical equipment (e.g., dragline or clamshell) operating either concurrently with the settling process or on a delayed basis after the sediment has had sufficient time to dewater partially or wholly. In some applications, it is preferable to have an intermediate handling step wherein a secondary dredge (e.g., a Mud Cat) recovers the sediment from the ISR basin and feeds it to a secondary basin. A secondary basin serves one or more of three functions:

• A secondary basin is needed to refine the clay-contaminated sediment of an ISR basin whose function is to produce a clean, fine-grained material, but which receives intermittent flow from the primary dredge (see Paragraph 226 for further explanation).

• If concurrent recovery of sediment from the ISR basin is desirable, but the ISR basin is too large for a simple, inexpensive mechanical handling system (see Figure 62), check the size of a secondary basin; it might be small enough for the inexpensive system.

• If delayed recovery of sediment is desirable, but primary dredge operation is too frequent for adequate draining/drying, staged use of

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* Densification techniques (discussed later in this chapter) may be used to hasten consolidation of the sediment to recover storage volume for subsequent disposal operations.

** A facility designed for the first function produces, as a by-product, sediment perfectly satisfactory for most uses (e.g., landfill, cover), even though this by-product generally is not as clean (clay-free) as sediment produced by a facility designed specifically for the latter purpose.

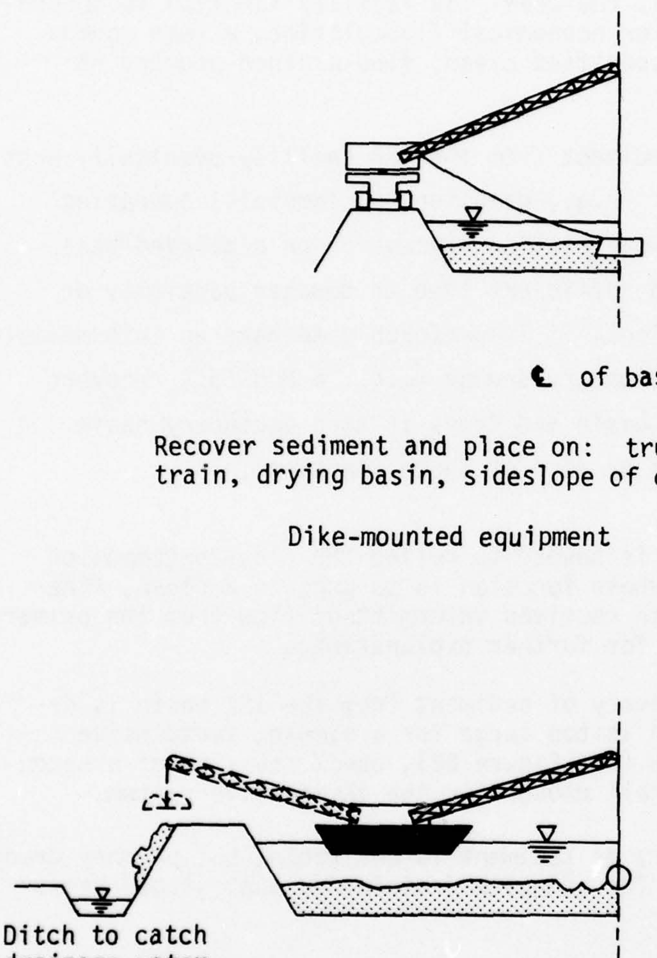

Figure 62. Mechanical Recovery of Sediment from Small Settling Basin

settling basins can be used, wherein one basin is allowed to drain/dry* while another is being filled. In some instances, staging small secondary basins might be cheaper than staging larger ISR basins.

Optional systems for recovering sediment from the ISR basin are shown in Table 17. Clearly, concurrent recovery from a small ISR basin and delayed recovery from any size ISR basin are economically preferable to the more complex systems for concurrent recovery from a large ISR basin. The latter systems add a handling step requiring more equipment and manpower.

226. Intermittent primary dredge operation affects the design and operation of the ISR and FSR facilities. We recommend cutting off overflow from the ISR basin via a gated weir coincidental with influent cutoff when the primary dredge goes off-line. With overflow stopped, retention of excess clay-sized particles in the ISR basin is increased. However, this only worsens an inevitable condition; once inflow is cut off, excessive retention (hereafter called "overretention") to some degree is unavoidable even if overflow continues. For instance, if overflow is not cut off, a fixed-crest weir yields flow rates varying anywhere from no- to full-flow as the water level in the basin cycles up and down in response to the on/off flow. The outflow might reach the full-flow (design) value only a small part of the time; the rest of the time, the water level is in transition and flow over the weir is less than full-flow, thereby causing overretention. Nor does a floating, constant-head weir prevent overretention. The outflow would be a constant, less than full-flow value until the weir hits stops setting maximum and minimum water levels. Once the weir hits the upper stop, the head and thus the outflow would approach the full-flow value; once the weir hits the lower stop, the head and outflow will drop toward zero. As with the fixed-crest weir, full-flow might be reached only part of the time, with overretention occurring the remainder of the time.

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* With the assistance of densification techniques, if desired.

Table 17

Optional Sediment Recovery Systems for ISR Basins

Recovery Schedule*	ISR Basin Size	
	Small	Large
Concurrent	Mechanical equipment (dragline, clamshell) mounted on dike or barge (see Figure 62)	Mechanical equipment mounted on dike of elongated settling basin (see Figure 63) or Mechanical equipment mounted on barge loading shallow-draft barges unloaded by dike-mounted mechanical equipment or Secondary dredge feeding a secondary basin served by mechanical equipment
Delayed	Mechanical equipment working on the surface of the sediment	

* Concurrent with on-going sedimentation; but not necessarily coinciding with primary dredge operation. Delayed to permit draining/drying (via natural means or densification techniques) to either:

- Establish a crust capable of supporting mechanical equipment for recovery of the underlying sludge for final dewatering elsewhere.

- Completely dewater the material as it sits in the ISR basin, followed by mechanical recovery for on-site use or disposal or off-site transport.

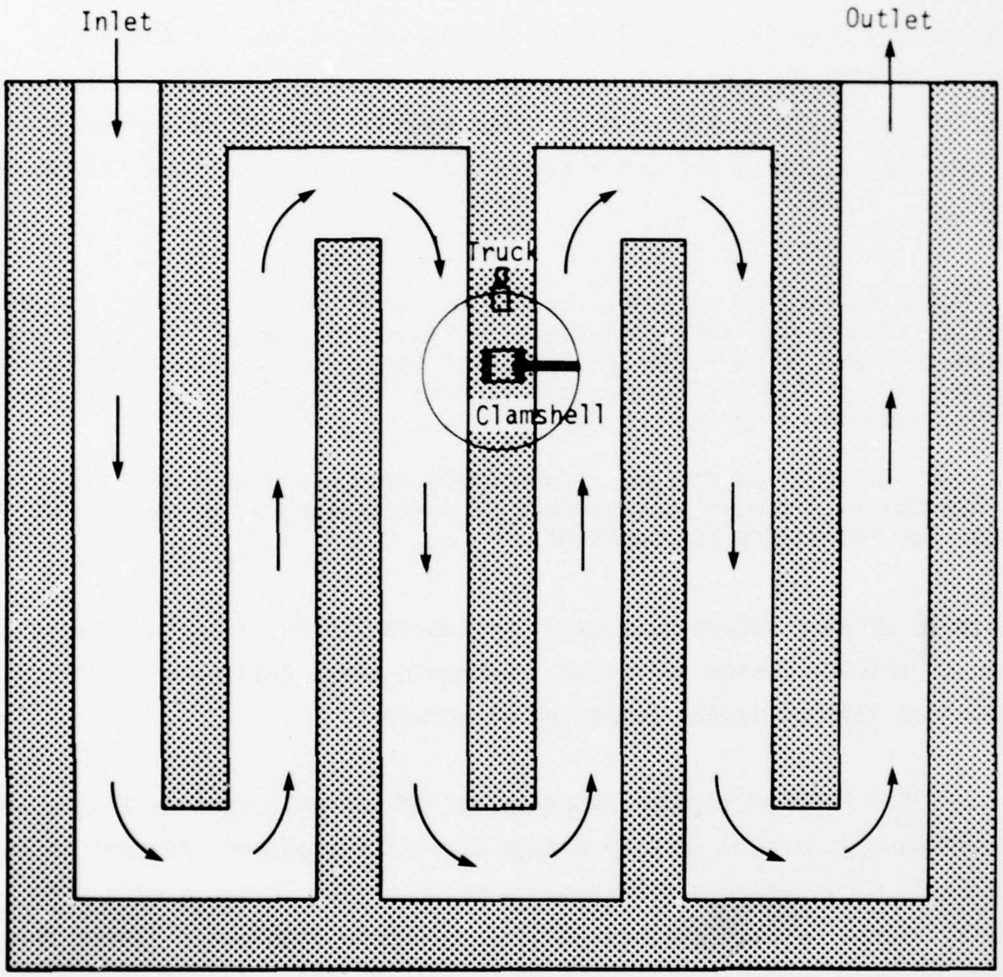

Figure 63. Dike-Mounted Mechanical Equipment for Sediment Recovery in Large ISR Basin

227. Overretention can be an advantage if the function of the ISR basin is to produce an FSR facility influent suitable for economical flocculation; if overretention drops the solids concentration below the design value, the feed rate of the flocculating agent might be cut accordingly (see Paragraph 251 for further discussion). Conversely, overrentention is undesirable if the function is to produce a clean, fine-grained product; a secondary basin must be used to refine out the excess clays. There are other advantages to cutting off the ISR basin's outflow:

- With outflow stopped, the FSR facility must handle only three distinct flows--full-flow, no-flow, or secondary dredge flow (if any). Whenever there is no flow, the FSR facility can be shut down, reducing O&M costs. If the outflow is not cut off, the FSR facility might operate several additional hours per day.

- With outflow stopped, a secondary dredge (if any) will be able to operate much longer without fear of running aground or running out of water for redredging the sediment.

Table 18 matches sediment recovery system to ISR facility function and type of primary dredge operation. Comments about design parameters are discussed further in the following paragraphs.

228. Referencing the hypothetical gradation curves in Figure 64: continuous, long-term primary dredge operation produces sediment in the ISR basin whose <u>average</u> gradation is shown by the "average retained" curve. Since coarser-grained particles tend to settle out faster than finer-grained particles, the <u>actual</u> gradation ranges from "coarser than average retained" near the basin's inlet to "finer than average retained" near the basin's outlet. In comparison, intermittent primary dredge operation produces sediment whose <u>average</u> gradation ranges from "average retained" when the dredge is operating to "incoming less colloids" when the dredge is off-line, because the flow through the basin drops to zero and all particles other than colloids settle out. The <u>actual</u> gradation when the dredge is operating is the same as that

Table 18

Matching Sediment Recovery System with ISR Facility Function and Primary Dredge Operation

Function of ISR Facility	Primary Dredge Operation*	SEDIMENT RECOVERY SYSTEM: Recovery Direct from ISR Basin		Recovery from Secondary Basin	
		Concurrent**	Delayed	Concurrent***	Delayed
Produce a clean fine-grained product	Intermittent	Neither concurrent nor delayed recovery is suitable because the ISR basin's sediment is contaminated with clay-sized particles when the primary dredge is off-line and the ISR basin's inflow and overflow are cut off.		A secondary dredge/secondary basin system working on a continuous, long-term basis can satisfactorily refine the ISR basin's contaminated sediment. In many cases, however, the secondary basin will be too large for concurrent sediment recovery by a simple, inexpensive mechanical handling system (Figure 62). The reason: the secondary basin is designed using the ISR basin's "incoming less colloids" gradation curve and an effluent adjusted for the presence of colloids in the water used to reslurrify the sediments.**** If a simple mechanical recovery system is not practical, delayed recovery is preferable because concurrent recovery requires a complex, expensive mechanical handling system (described in Table 17 for use with a medium to large ISR basin).	Delayed sediment recovery is suitable regardless of the size of the secondary basin provided the secondary dredge's on-line period is long enough to build up a thick bed of clean product that is not significantly contaminated during the transition periods when the secondary dredge first begins and finally terminates its operation.

Table 18 (Continued)

Function of ISR Facility	Operation*	SEDIMENT RECOVERY SYSTEM: Recovery Direct from ISR Basin: Concurrent**	Recovery Direct from ISR Basin: Delayed	Recovery from Secondary Basin: Concurrent***	Recovery from Secondary Basin: Delayed
	Continuous, long-term	Concurrent recovery is suitable since full-flow settling conditions exist at all times (except when the basin's flow is in transition when the primary dredge first begins and finally terminates operation).	Delayed recovery is suitable provided the primary dredge's on-line period is long enough to build up a thick bed of clean product that is not significantly contaminated during the start and stop transitions.	Clay contamination of sediments in the ISR basin is generally negligible with continuous, long-term primary dredge operation; a secondary basin is not needed to refine the sediment. Thus, to justify its use, a secondary basin must provide concurrent recovery at a cheaper rate than available with concurrent recovery from the ISR basin. This is possible only if the secondary basin is small enough to be served by a simple, inexpensive mechanical handling system (see Table 17). In many cases, however, the secondary basin's size will be unacceptably large because it is designed using the ISR basin's "incoming less colloids" gradation curve and an effluent adjusted for the presence of colloids in the water used to reslurrify the sediments.****	In some situations, delayed recovery is desirable, but dredging operations are too frequent to permit adequate draining/drying. Staged use of settling basins can be used, wherein one basin is allowed to drain/dry while another is being filled. If the secondary basin is substantially smaller than the ISR basin, staged use of secondary basins will require less land than staged use of ISR basins. However, the additional operating costs incurred with the extra handling step (secondary dredging) generally more than offset the savings in land costs.
Produce a specific overflow solids concentration for economical flocculation in the FSR facility	Intermittent	Both concurrent and delayed recovery are suitable. Overretention of clays has no significant impact except to delay "Delayed" recovery somewhat because finer-grained material dewaters/dries at a slower rate.		In this application, overretention of clays is not a disadvantage; a secondary basin is not needed to refine the sediment. Thus, the comments immediately above apply in this case as well.	The comments immediately above apply to this application.

Table 18 (Concluded)

Function of ISR Facility	Primary Dredge Operation*	SEDIMENT RECOVERY SYSTEM: Recovery Direct from ISR Basin		Recovery from Secondary Basin	
		Concurrent**	Delayed	Concurrent***	Delayed
	Continuous, long-term	Both concurrent and delayed recovery are suitable.		For this application, the corresponding comments for the "Product" case apply.	The comments immediately above apply to this application.

* Intermittent = one or two shifts per day or short-term continuous use, say for two days, then shutdown. Continuous, long-term = several days uninterrupted operation.

** Recovery concurrent with on-going sedimentation in the ISR basin; but not necessarily coincident with primary dredge operation.

*** Recovery concurrent with on-going sedimentation in the secondary basin; but not necessarily coincident with either primary or secondary dredge operation.

**** See Paragraphs 226-230 for a detailed discussion; see Paragraphs 243-245 for example computations.

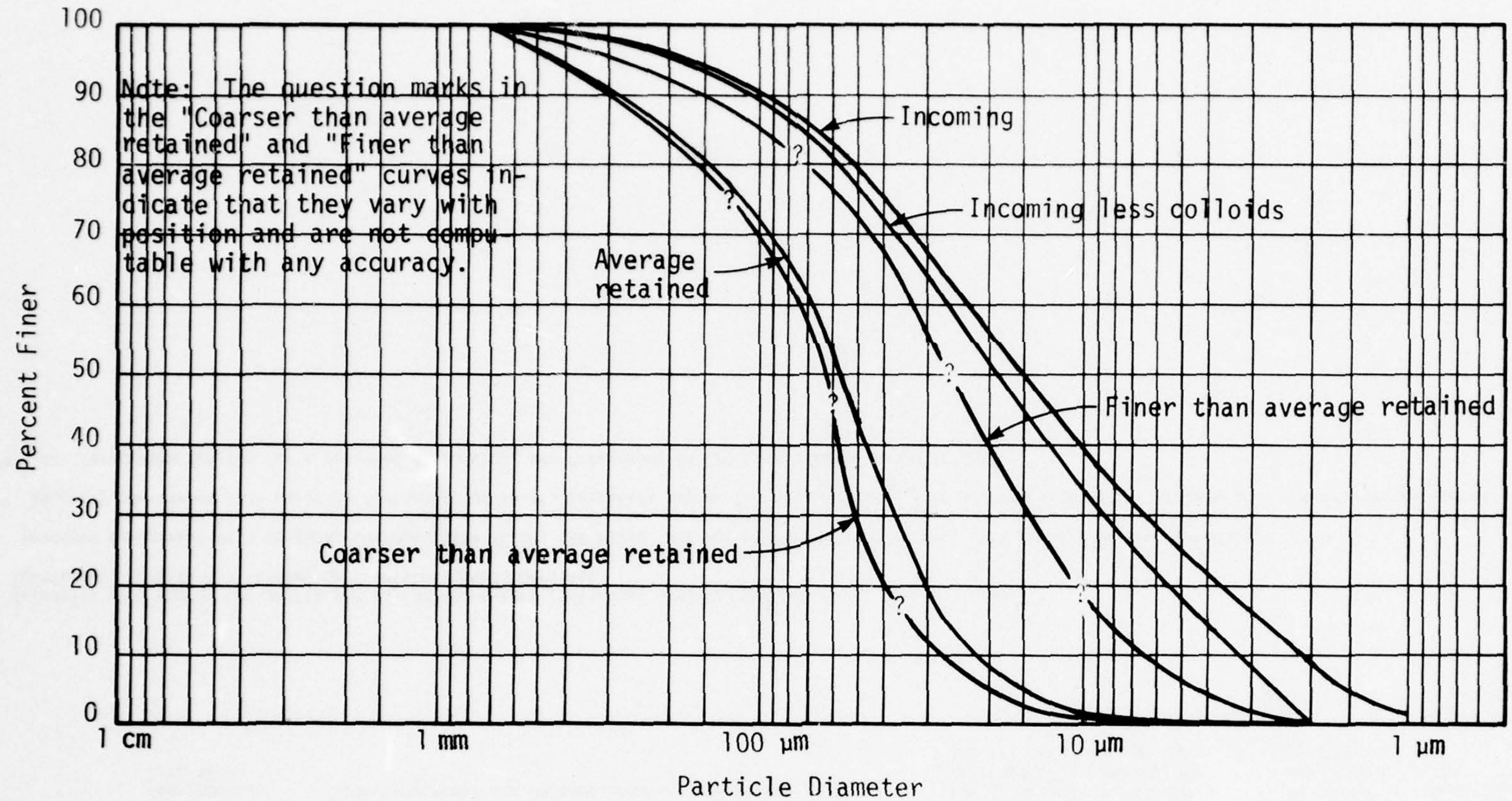

Figure 64. Example ISR Basin Gradation Curves

for long-term operation. But when the dredge stops pumping, the basin receives a thin overall dusting of noncolloidal particles finer than "incoming less colloids." This dusting is graded from quicker settling, slightly larger particles on the bottom to the verv finest settleable particles on top.

229. Clearly, it is incorrect to design the secondary basin assuming the "average retained" gradation curve represents the material entering the basin. Consider such an improperly designed secondary basin in an ISR facility whose function is to produce a clean fine-grained product: "finer than average retained" sediment recovered by the secondary dredge from the outlet half of the ISR basin will contaminate the product because excess clays will be retained in the secondary basin. If, instead, the function is to produce a low slurry solids concentration for economical flocculation in the FSR facility, then "finer than average retained" material will cause excessive bypassing of suspended matter.

230. Thus, regardless of the ISR facility's function, the secondary basin must be designed using a conservative gradation curve, i.e., one as fine or finer than anticipated under normal operating conditions. We recommend using the "incoming less colloids" gradation curve with appropriate adjustments to the secondary basin's output criterion to account for the presence of colloids in the water used by the secondary dredge to reslurrify the ISR basin's sediment.

- Intermittent primary dredge operation-The recommended design gradation represents the worst (finest) average sediment gradation. The thin dusting of particles finer than "incoming less colloids" normally does not constitute an even worse (finer) case because, during recovery by the secondary dredge, this dusting is thoroughly mixed with underlying "retained" materials.

• Continuous, long-term primary dredge operation--The retained material ranges from "coarser than average retained" to "finer than average retained."* Since the latter is somewhat coarser than the "incoming less colloids" gradation, the recommended design gradation is actually worse (finer) than the worst (finest) gradation to be found--a very conservative criterion.

INITIAL SOLIDS REMOVAL FACILITY--DESIGN PROCEDURE

231. The procedure for designing an ISR facility--including ISR basin and secondary basin--is shown in this section. Numerous examples are provided to illustrate the types of inputs needed and the computational processes involved. The District should note and heed the cautions presented at the end of this section.

CMSP Facility Performance

232. The first step is to assess the solids retention and by-pass of the CMSP facility (if any). There are two major differences between this analysis and earlier analyses done per the procedures shown in Chapters 5 and 6: Chapters 5 and 6 used the median gradation curve and the "ideal" settling theory to estimate production rates of coarse-grained material; this chapter, in which the ISR facility is designed, uses the fine-grained boundary of the gradation envelope and an adaptation of Hazen's settling theory for real basins.

233. Given the following example: direct feed from a hydraulic pipeline dredge to the CMSP facility where a classifier is used (per alternative 2) to produce ASTM Fine Aggregate from the incoming DM slurry.

* Except for a light dusting of clays during the transition periods when the primary dredge first starts up and finally shuts down. This light dusting poses no anomaly, however, because it is thoroughly mixed with underlying coarser sediments during recovery by the secondary dredge.

- Primary dredge discharge rate (Q) = 16,000 gpm (8 hours/day)
- Solids concentration by dry weight (C) = 10%
- Solids specific gravity (SG) = 2.65
- Incoming gradation curve shown in Figure 65 (also shown as the fine-grained boundary of the gradation envelope in Figure 11).

The CMSP facility is designed to remove a major portion of the ≥150-μm material. The portion of any given particle size that will be removed can be calculated from Equation 6:

$$P = 1 - [1 + 0.001325\ D^2/(Q/A)]^{-1} \qquad \text{Equation 6*}$$

where: D = particle size, μm
Q/A = surface loading rate, gpm/ft^2
P = proportion of particles of size D retained

If the surface loading rate Q/A is expressed in terms of gpm/acre, this equation becomes

$$P = 1 - [1 + 57.73\ D^2/(Q/A)]^{-1}$$

234. The method of computing the gradation curves of the solids retained and bypassing the CMSP facility is illustrated in Table 19. The first row lists the percentage of influent DM in various particle size ranges (as read off the DM gradation curve). The second row is calculated from Equation 6 using the median particle size in each range and a surface loading rate of 15 gpm/ft^2, the value recommended by

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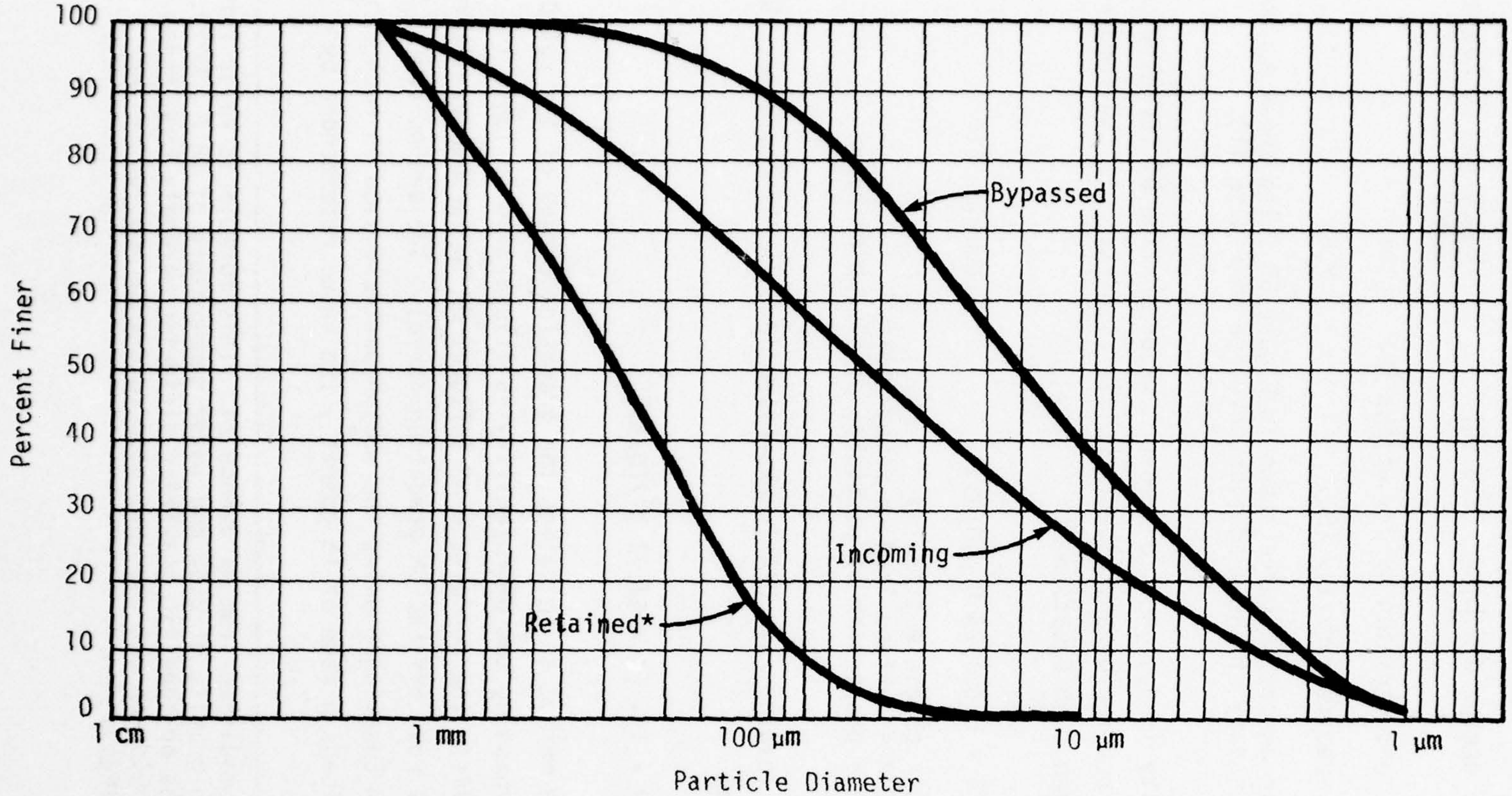
* Adopted and modified from Reference 24. This formula is valid for a solids specific gravity of 2.67 and water temperature of 68°F (20°C). For temperatures or specific gravities differing markedly from these values, one should consult the indicated reference and modify the formula accordingly.



* Note: Retained material can be processed to yield ASTM or other "spec" products with the remainder constituting non-spec coarse material which might be useful (e.g., as landfill) or might be waste.

Figure 65. Gradation Curves for Coarse Material Separation and Processing Facility

Table 19

Sample Calculation of Solids Retention and Bypass for Coarse Material Separation and Processing Facility

	Particle Size Range, μm	≤2*	2-10	10-20	20-30	30-50	50-75	75-100	100-150	150-200	200-500	>500	
	Median Particle Size, μm	--	6	15	25	40	62	87	125	175	350	500	Totals
Row	Item												
1	Incoming gradation, percent	6	19	11	7	9	6	6	6	6	12	12	100
2	Portion retained (Equation 6)	0*	.003	.019	.052	.124	.254	.401	.580	.730	.915	>.951	--
3	Percent retained (Row 1 x Row 2)	0	.1	.2	.4	1.1	1.5	2.4	3.5	4.4	11.0	11.5	36.1
4	Percent bypassed (Row 1 - Row 3)	6	18.9	10.8	6.6	7.9	4.5	3.6	2.5	1.6	1.0	0.5	63.9
5**	Normalized retained, percent (100 x Row 3/Σ Row 3)	0	0.3	0.6	1.1	3.0	4.2	6.6	9.7	12.2	30.5	31.9	100
6***	Normalized outflow, percent (100 x Row 4/Σ Row 4)	9.4	29.6	16.9	10.3	12.4	7.0	5.6	3.9	2.5	1.6	0.8	100

* Particles <2 μm in size are colloidal, hence nonsettling.

** Result is gradation curve of retained solids.

*** Result is gradation curve of bypassed solids.

classifier/clarifier manufacturers to size equipment to retain ⩾150-μm material. The computed proportionality factors (row 2) are applied to the corresponding figures in the first row to calculate the amount retained (row 3) and amount bypassed (row 4). These results are normalized to obtain rows 5 and 6 and the resulting figures are plotted in Figure 65. Note that according to the "real" settling theory, 36 percent of the solids are removed by the CMSP facility;* 64 percent are bypassed.

Single-Stage Solids Removal

235. The second step is to examine the feasibility of single-stage solids removal, i.e., with the "ISR" facility only, no "FSR" facility.** Single-stage solids removal is a viable option only when a clean, fine-grained product is not a major goal--sediment from a single-stage system will be contaminated by much clay-sized material.

236. It is assumed that any water losses in the CMSP facility are offset by additions of wash water, etc.; thus, the flow rate entering and leaving the CMSP facility is identical. In this example, the effluent conditions from the CMSP (therefore, the inflow conditions to the ISR facility) are:

- 16,000 gpm
- 275 tph solids***
- Gradation curve of "bypassed" material shown in Figure 65

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* Comparing very favorably with the 40-percent figure used in Chapters 5 and 6 as read off the median gradation curve for ⩾150-μm particles. In the real case, however, some ⩾150-μm material is bypassed; some <150-μm material is retained.

** "ISR" and "FSR" are obviously misnomers with single-stage solids removal, since there is only the one stage.

*** 0.64 (the bypassed fraction) x 430 tph (the total solids delivery rate from Figure 8 given 16,000 gpm and 10 percent solids concentration).

237. At this point, a two-part test is performed to determine if single-stage solids removal is practical for treating the given influent.* The first part of the test is a quick check to determine if applicable effluent standards can be met if all noncolloidal solids are removed. If the result is negative, there is no need to go to the second part of the test, which is a more complex computation for sizing the basin to retain enough solids to meet the effluent standard.

238. Part 1 of single-stage feasibility test--input conditions:

- Inflow solids percentage by dry weight, C_1
- Required effluent concentration C_2 in g/l
- Gradation curve of material entering ISR facility ("bypassed" curve in Figure 65)
- 2.65 solids SG

C_1 is found using the formula $C_1 = 100/[Q/(4SDR) - 1/SG + 1]$ from Figure 8, where SDR = 275 tph solids and Q = 16,000 gpm; therefore $C_1 = 6.6$ percent. The gradation curve of the solids entering the ISR basin shows the percentage of colloidal solids ($\leqslant 2\ \mu$) is 9 percent. Thus, colloids are 0.59% by dry weight = 0.09 x 6.6% of the slurry. Convert this to g/l via Equation 7:

Solids concentration (g/l) = $1000C/[100 - C(SG-1)/SG]$ Equation 7

i.e., 5.9 g/l = $1000 \times 0.59/[100 - 0.59\ (2.65-1)/2.65]$.

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* In this example, the test is applied to the CMSP facility's effluent. If CMSP is not included, the test is applied to the incoming DM as fed on site by the primary dredge or by secondary dredge or mechanical handling equipment.

If this figure exceeds C_2, then single-stage removal cannot meet the required standard.*

239. Part 2 of single-stage feasibility test--Assuming for the moment that 10 g/l is the applicable effluent standard, then single-stage removal is possible, but the test must be used to assess whether single-stage removal is really practicable.

Input conditions:

- Those used in Part 1
- Inflow rate = 16,000 gpm

A trial-and-error procedure is used to calculate the area of the single settling basin that will achieve the required degree of clarification as computed from Equation 2:

$$R = 100[1 - (100/C_1 - 1)/(1000/C_2 - 1)]$$

where: R = the percentage of solids that must be removed.

In this example, $R = 85.7 = 100[1 - (100/6.6 - 1)/(1000/10 - 1)]$.

Using a method similar to that shown in Table 19, the percentage of solids retained in various size ranges can be calculated for an assumed basin area.** If the total percentage retained differs from R, iterate using a larger basin area if the percentage is low; use a smaller area if the percentage is high. Table 20 shows that for the assumed effluent

* As demonstrated earlier, although a flocculating agent could be used to make single-stage removal possible, the high solids concentrations at this point makes this concept economically uncompetitive with two-stage solids removal.

** The assumed basin area determines the surface loading rate, Q/A, for that trial.

Table 20

Trial-and-Error Determination of Size of Single-Stage Solids Removal Basin

Row	Item	⩽2*	2-5	5-10	10-20	20-30	30-60	>60	Totals
	Particle Size Range, μm	⩽2*	2-5	5-10	10-20	20-30	30-60	>60	Totals
	Median Particle Size, μm	--	3.5	7.5	15	25	45	60	
1	Incoming gradation curve, percent	9	16	14	17	11	16	17	100
	20-acre basin (Q/A = 800 gpm/acre)								
2	Portion retained (Equ.6)	0	.469	.802	.942	.978	.993	.996	
3	Amount retained (Row 1 x Row 2)	0	7.5	11.2	16.0	10.8	15.9	16.9	78.3
	45-acre basin (Q/A = 355.6 gpm/acre)								
2	Portion retained (Equ.6)	0	.665	.901	.973	.990	.997	.998	
3	Amount retained (Row 1 x Row 2)	0	10.6	12.6	16.5	10.9	16.0	17.0	83.6
	68-acre basin (Q/A = 235.3 gpm/acre)								
2	Portion retained (Equ.6)	0	.750	.932	.982	.994	~1	~1	
3	Amount retained (Row 1 x Row 2)	0	12.0	13.1	16.7	10.9	16.0	17.0	85.7

* Particles ⩽2 μm in size are colloidal, hence nonsettling.

standard of 10 g/l, a large basin area, 68 acres (which is increased to 75 acres in accordance with the cautionary recommendations at the end of this section), is needed to achieve single-stage removal. If the candidate disposal site lacks sufficient area, a two-stage solids removal system must be used. If adequate area is available, then the District must weigh the relative costs of a simple, but relatively large single-stage facility versus a smaller, but more complex two-stage facility requiring costly flocculation to function properly. The single-stage facility, because of its characteristically large basin, is an excellent candidate for a secondary basin if concurrent sediment removal is desirable. The design procedure for a secondary basin is illustrated later in this example.

ISR Basin for Two-Stage Solids Removal System

240. The third step is to size the ISR basin for two-stage solids removal. In a two-stage system, the ISR basin can be sized to serve either of two distinct functions discussed earlier: to yield an effluent solids concentration for economical flocculation in the FSR facility; or to provide a clean, fine-grained product (for example, by retaining silts and bypassing most clay-sized particles).

241. To illustrate the first of these two functions, an effluent concentration of 20 g/l has been selected based on the discussion of flocculation in Reference 24.* With 6.6 percent influent concentration and 20-g/l effluent concentration, Equation 2 shows the resulting solids retention requirement is 71.1 percent for the ISR facility. The ISR basin size is determined in Table 21 on a trial-and-error basis using the same procedure used in Table 20. An 8.6-acre basin is found to remove the necessary quantity of solids. This value is increased to 10

* For detailed information regarding flocculating agents and requirements for practical and economical flocculation, consult reports from DMRP task areas 6B07 and 6C04.

Table 21

Trial-and-Error Determination of Size of Initial Solids Removal Basin for Two-Stage System

Row	Item	≤2*	2-5	5-10	10-20	20-30	30-60	>60	Totals
	Particle Size Range, μm	≤2*	2-5	5-10	10-20	20-30	30-60	>60	Totals
	Median Particle Size, μm	--	3.5	7.5	15	25	45	60	
1	Incoming gradation curve, percent	9	16	14	17	11	16	17	100
	10-acre basin (Q/A = 1600 gpm/acre)								
2	Percent retained (Equ.6)	0	.307	.670	.890	.958	.987	.992	
3	Amount retained (Row 1 x Row 2)	0	4.9	9.4	15.1	10.5	15.8	16.9	72.6
	8.5-acre basin (Q/A = 1882.4 gpm/acre)								
2	Percent retained (Equ.6)	0	.273	.633	.873	.950	.984	.991	
3	Amount retained (Row 1 x Row 2)	0	4.4	8.9	14.8	10.4	15.7	16.8	71.0
	8.6-acre basin (Q/A = 1860.5 gpm/acre)								
2	Percent retained (Equ.6)	0	.275	.636	.875	.951	.984	.991	
3	Amount retained (Row 1 x Row 2)	0	4.4	8.9	14.9	10.5	15.7	16.8	71.2
4	Normalized retained (100 x Row 3/Σ Row 3)	0	6.2	12.5	20.9	14.7	22.1	23.6	100

*Particles ≤2 μm in size are colloidal, hence nonsettling.

acres in accordance with the cautionary recommendations at the end of this section. The figures in Table 21 can be normalized to show the average gradation curve of the retained solids (see Figure 66); but, as discussed earlier, retained and bypassed gradations are only valid for the case of constant flow-through. When the primary dredge is off-line, ISR basin inflow and outflow are cut off; clay-sized particles begin to settle out, shifting the "average retained" gradation curve toward the "entering" curve and reducing the solids concentration in the trapped water below the design effluent value.

242. If, instead, the ISR basin is to produce a particular fine-grained product, then the area of the basin is sized such that the gradation curve of the settled material is acceptable. For example, it might be specified that no more than 10 percent of the material should be ≤ 10 μm in size. ISR basin area is then determined using the same procedure as in Table 21 with the above criterion being the goal.*

Secondary Basin Design

243. The fourth step is to design a secondary basin if the size of the ISR basin is too large for economical mechanical recovery of the settled materal. This certainly is the case in both the cases illustrated: the single-stage case with a 75-acre ISR basin; and the two-stage case with a 10-acre ISR basin. Actually, one or more secondary dredges and basins might be needed depending on any of several factors: the sediment storage capability of the ISR basin relative to the solids retention rate; a work schedule limited perhaps by the upcoming winter season; or a need to utilize the secondary dredge(s) and mechanical handling equipment at other disposal sites as well.

* Outflow concentration is not the prime consideration in sizing the ISR basin in this situation. The value of the outflow concentration is needed, however, as an input to the design of the FSR facility.

* The "average retained" curve shown is based on the full-flow case. When the primary dredge goes off-line, finer particles begin to settle out, shifting the "average retained" curve back toward the "entering" curve. Thus, with intermittent primary dredge operation, the average gradation of the retained sediment can fall anywhere in the shaded area.

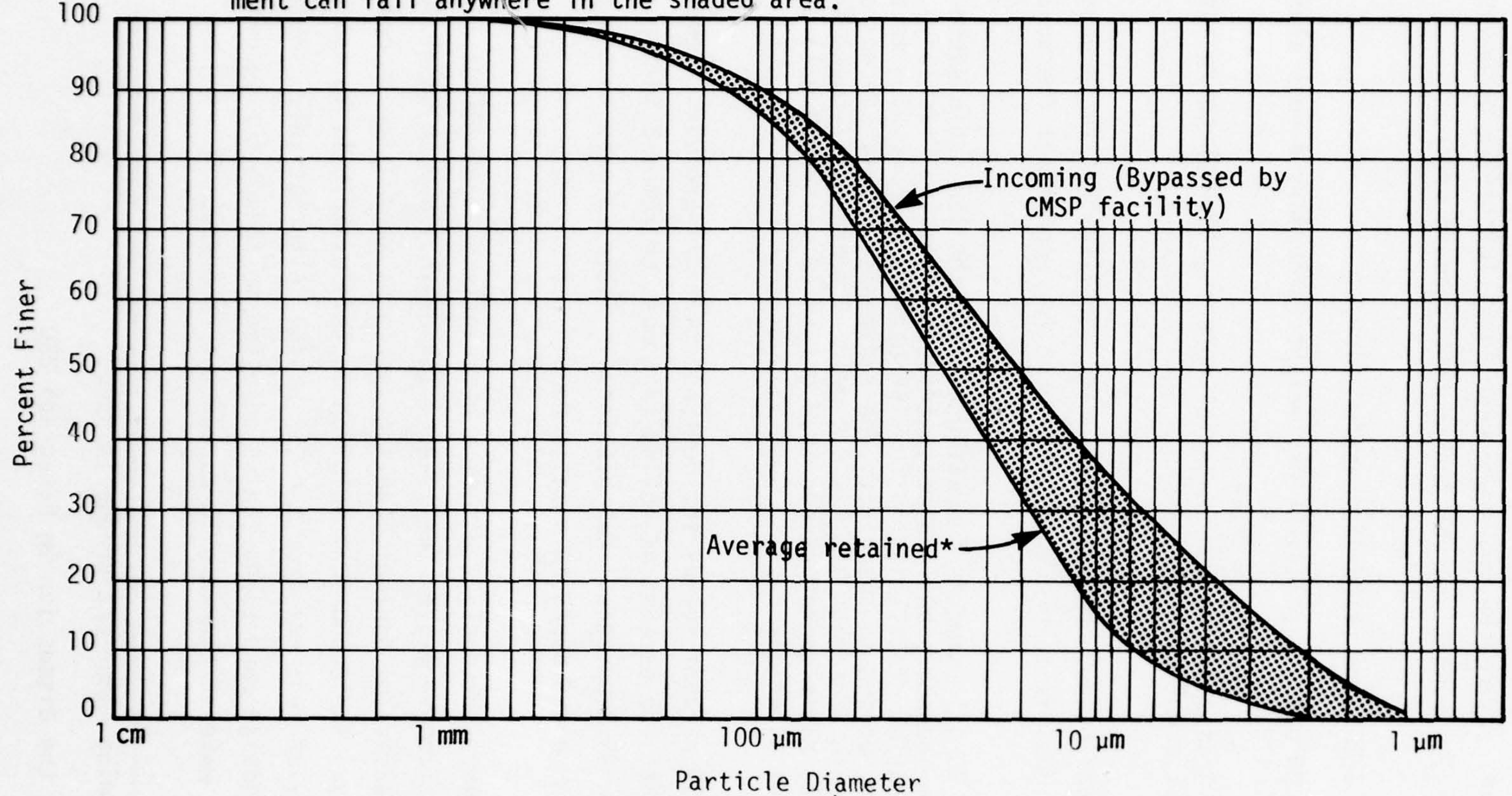

Figure 66. Gradation Curves for Initial Solids Removal Basin Yielding Selected Effluent Solids Concentration

244. Using the two-stage case for illustrative purposes, the input design conditions for the secondary basin are:

- 2,000 gpm (secondary dredge flow)*

- 20 percent solids by dry weight (secondary dredge slurry concentration)*

- Gradation curve of material entering the ISR basin less colloids** (Table 22 and Figure 67)

The output design condition (assuming for illustrative purposes that the primary goal is to produce an effluent for economical flocculation) is:

- 20 g/l (same as the effluent from the ISR basin since effluent from the secondary basin also is treated in the FSR facility) less the concentration of colloids in the ISR basin's water (which is used by the secondary dredge to reslurrify the sediments). This concentration, computed in Paragraph 238, is 5.9 g/l. Therefore, effluent from the secondary basin cannot exceed 14.1 g/l (= 20 g/l - 5.9 g/l) of non-colloidal material.

With a 20 percent solids influent and 14.1-g/l effluent, Equation 2 shows that the percent of solids that must be removed in the secondary basin is 94.3 percent. Calculations in Table 23 show that a basin between 8 and 9 acres in size is needed.

245. Obviously, this size basin offers no advantage in terms of sediment recovery over the 10-acre ISR basin; in both cases, a complex and expensive mechanical handling system is needed for concurrent recovery. The economical solution in this example is to use delayed recovery of sediment from the ISR basin. Alternatively, input and output design conditions can be adjusted to reduce the secondary basin size to make it amenable to concurrent recovery:

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* Assuming a Mud Cat dredge is used.

** Per the discussion in Paragraph 230.

Table 22

Derivation of the ISR Basin's "Incoming Less Colloids"
Gradation Curve for Secondary Basin Design

Particle Size Range, μm	≤2*	2-5	5-10	10-20	20-30	30-60	>60	Totals
ISR basin's "incoming" gradation curve (from Figure 66)	9	16	14	17	11	16	17	100
ISR basin's "incoming" gradation curve less colloids	0	16	14	17	11	16	17	91
ISR basin's "incoming less colloids" gradation curve (normalized), see Figure 67	0	17.6	15.4	18.7	12.1	17.6	18.7	100

*Particles ≤2 μm in size are colloidal, hence nonsettling.

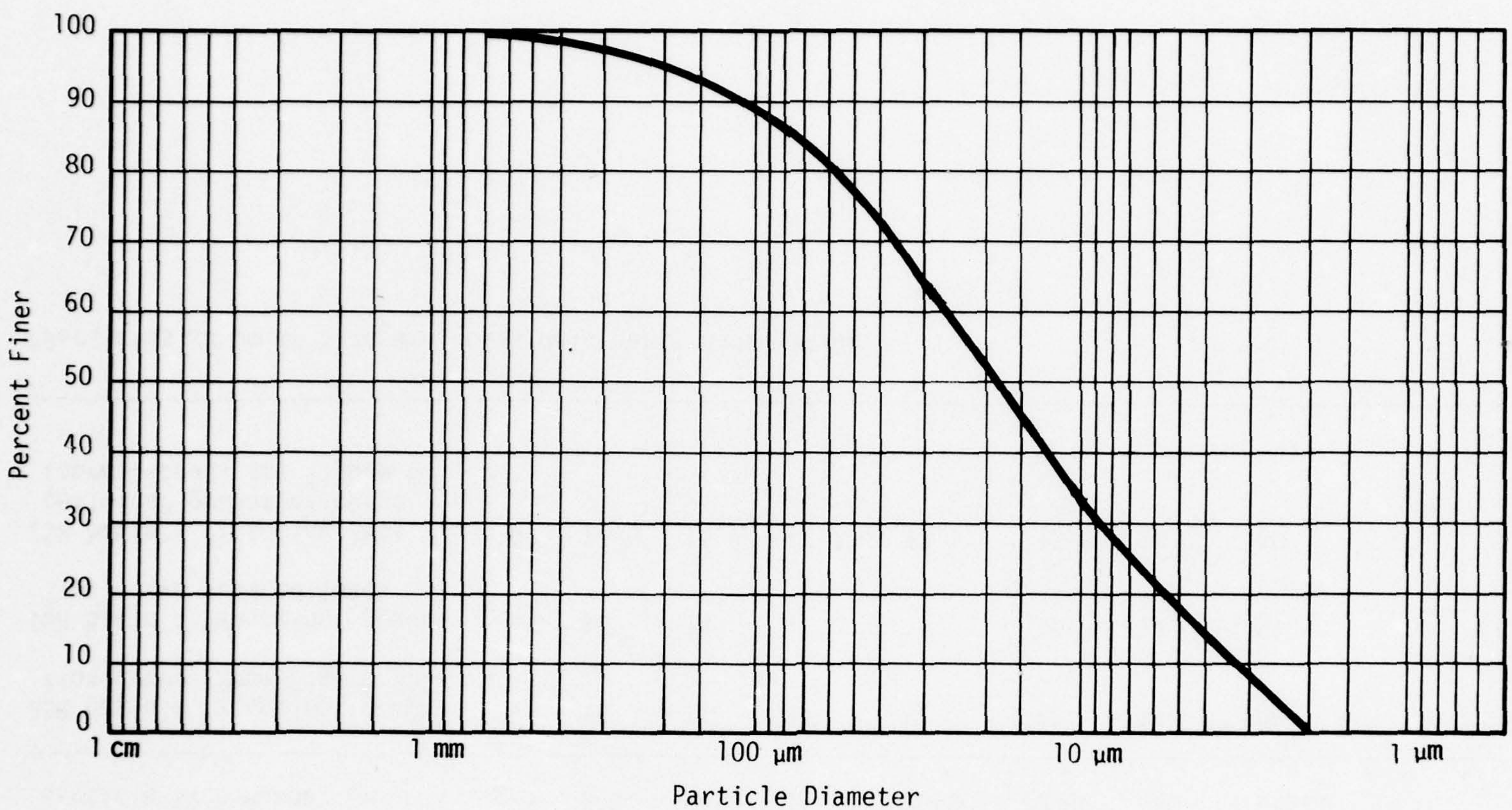

Figure 67. Design Gradation Curve for Secondary Basin--ISR Basin's "Incoming Less Colloids" Gradation Curve

Table 23

Trial-and-Error Determination of Secondary Basin Size

Row	Item	≤2*	2-5	5-10	10-20	20-30	30-60	>60	Totals
	Particle Size Range, μm	≤2*	2-5	5-10	10-20	20-30	30-60	>60	Totals
	Median Particle Size, μm	--	3.5	7.5	15	25	45	60	
1	Incoming gradation curve, percent	0	17.6	15.4	18.7	12.1	17.6	18.7	100
	3-acre basin (Q/A = 666.7 gpm/acre)								
2	Portion retained (Equ. 6)	0	.515	.830	.951	.982	.994	.997	
3	Amount retained (Row 1 x Row 2)	0	9.1	12.8	17.8	11.9	17.5	18.6	87.7
	8-acre basin (Q/A = 250 gpm/acre)								
2	Portion retained (Equ. 6)	0	.739	.929	.981	.993	.998	.999	
3	Amount retained (Row 1 x Row 2)	0	13.0	14.3	18.3	12.0	17.6	18.7	93.9
	9-acre basin (Q/A = 222.2 gpm/acre)								
2	Portion retained (Equ. 6)	0	.761	.936	.983	.994	~1	~1	
3	Amount retained (Row 1 x Row 2)	0	13.4	14.4	18.4	12.0	17.6	18.7	94.5

*Particles ≤2 μm in size are colloidal, hence nonsettling.

• Select a flocculating agent capable of handling a greater solids concentration. For instance, a FSR facility influent requirement of 40 g/l instead of 20 g/l reduces the solids retention needs to 85.9 percent in the above example. This requirement can be satisfied by a secondary basin of 3 acres (rounded up from 2.4 acres), which lends itself reasonably well to mechanical recovery in a 100-foot x 1300-foot layout.

• Reduce the secondary dredge's slurry concentration. Dropping the concentration from 20 to 10 percent changes the solids retention to 87.1 percent. This requirement also can be satisfied by a secondary basin of about 3 acres (rounded up from 2.8 acres).

• Reduce the secondary dredge's flow rate. Decreasing the flow rate from 2000 to 1000 gpm halves the size of the secondary basin.

Unfortunately, each of the above adjustments compromises economics in other ways. A higher solids concentration capability requires either more flocculating agent or a more expensive flocculating agent. Reducing the secondary dredge's performance lengthens the working time the dredge must be on duty, thereby increasing O&M costs. Clearly delayed recovery directly from the ISR basin is preferable, if at all possible.

Cautions in Designing the Initial Solids Removal Facility

246. The District should exercise due caution when using the procedures in this section. Experience in applying these methods to numerous examples has shown the following characteristics:

• Basin area is extremely sensitive to changes in solids retention requirements or, conversely, solids retention is relatively insensitive to changes in basin area. In the example computations above (Table 20), more than tripling basin area (from 20 to 68 acres) increased retention in the single-stage case by a factor of only about 10 percent.

• Basin area is extremely sensitive to changes in C_1 (influent concentration) and C_2 (effluent concentration). Modest changes in C_1 or C_2 are reflected by small changes in R (solids retention). But, as noted in the first point, basin area is extremely sensitive to changes in retention requirements. Even if C_2 is fixed for design purposes, C_1 can vary greatly depending on what is introduced from the primary dredge (which can experience large variations in solids concentration) or from a prior solids removal process (whose performance in turn is sensitive to influent variations, the vagaries of weather, etc.).

• Basin area is extremely sensitive to changes in gradation curve. Discrepancies in sampling, laboratory analyses, plotting, and reading off the plot will cause shifts in a basin's solids retention performance (as computed via Equation 6), which, in turn, can cause large changes in basin area.

• Basin area is moderately sensitive to changes in gradation increments used in the tabular trial-and-error computations (exemplified by Table 20). Supposedly, the finer the breakdown of gradation, the more accurate the results. However, because other, much larger sources of error are involved, we question the value of trying to "refine" the results.

247. Because of these (and other lesser) inherent sources of error in the basin sizing process, the methodology incorporates and recommends many conservative assumptions (i.e., those tending to enhance solids retention or, alternatively, increase basin size):

• The equation for P has been adjusted to represent very poor settling conditions within the basin.

• We recommend the District input the highest anticipated influent concentration, C_1 (e.g., input the maximum solids concentration that could reasonably be expected from the dredge).

• We recommend the District size basins on the basis of the fine-grained boundary of the gradation curve envelope.

• In addition, we suggest that the computed basin area be increased by about 10 percent (e.g., 10 percent plus rounding up to the next whole acre) to take care of small, random variations (e.g., in gradation curve or solids specific gravity) and to reflect the fact that settling theory is definitely an art, not a science. This adjustment would increase the average annual cost (including amortization and O&M expenses) by a small amount (much less than 10 percent).

FINAL SOLIDS REMOVAL FACILITY

248. The final solids removal (FSR) facility receives the overflow from the ISR facility and removes a sufficient amount of the remaining, predominantly fine-grained suspended solids to comply with

whatever effluent standards are applicable. Two practical FSR systems were identified, both of which rely on flocculation to agglomerate clay- and colloid-sized particles into flocs which then act like larger equivalent particles:*

- Flocculation followed by conventional gravity settling (Figure 68).

- Flocculation followed by high-rate settling (Figure 69).

249. In addition, consideration was extended to flocculation followed by any of a variety of filtration systems; but filtration systems were found to be unsuitable for use in the FSR facility (Table 24). The most common deficiencies were:

- Inability to handle solids concentrations as high as those entering the FSR facility--in most cases, it is impossible for an ISR facility to reduce the slurry's solids concentration to the influent limit of these filtration systems.**

- Prohibitive operating costs--Reference 24 concludes that with typical solids concentrations in the FSR facility's influent (>> 1 g/l), filter media fine enough to provide significant removal efficiencies in a compact unit tend to clog quickly; downtime and costs for

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* Flocculation is almost always needed for slurries from maintenance dredging projects; the proportion of very fine particles is too great in most cases for natural, unassisted settling alone to provide sufficient removal to meet applicable effluent standards. As noted in the footnote to Paragraph 222, flocculation costs are greatly reduced if the DM slurry has had its solids concentration reduced: this, of course, is the function of the ISR facility. In the case cited, the cost of treating a slurry containing about 10 percent solids by weight is about $0.56/cy of in situ DM; with a solids concentration of 20 g/l (about 2 percent by weight) or less, this costs drops to about $0.035/cy.

** In Paragraphs 235-239, an example DM disposal operation was analyzed. It was shown that, for this example, an ISR facility could not produce an effluent with less than 5.9 g/l; and even a comparatively lenient 10 g/l (with which most filtration systems cannot cope) required a huge (75-acre) basin.

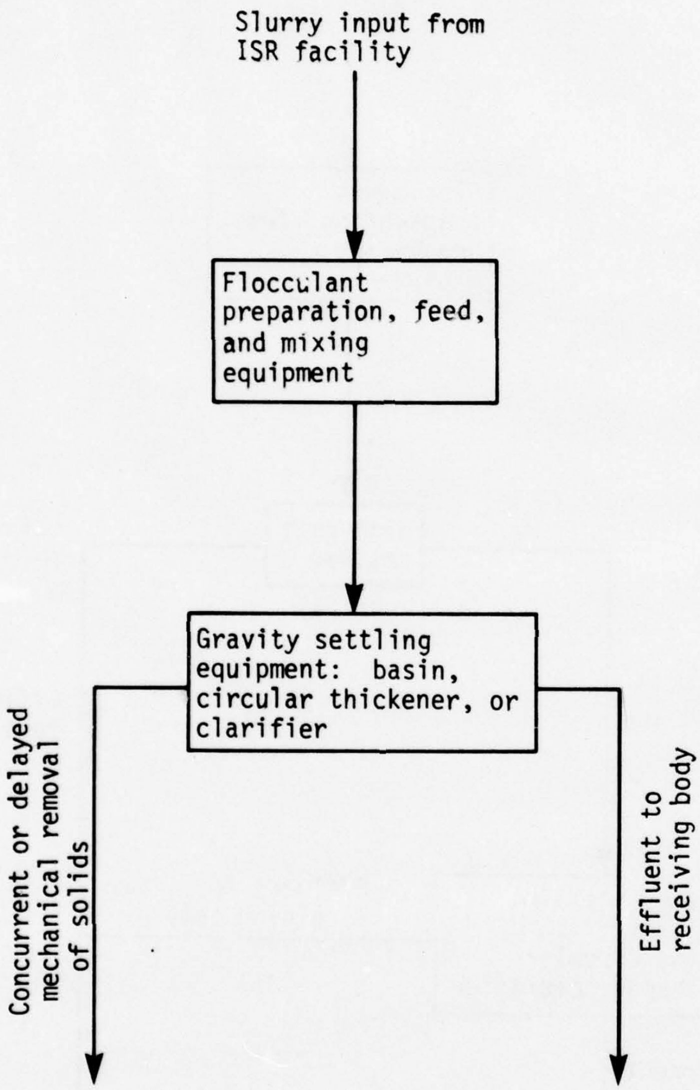

Figure 68. FSR Facility--Gravity Settling Option

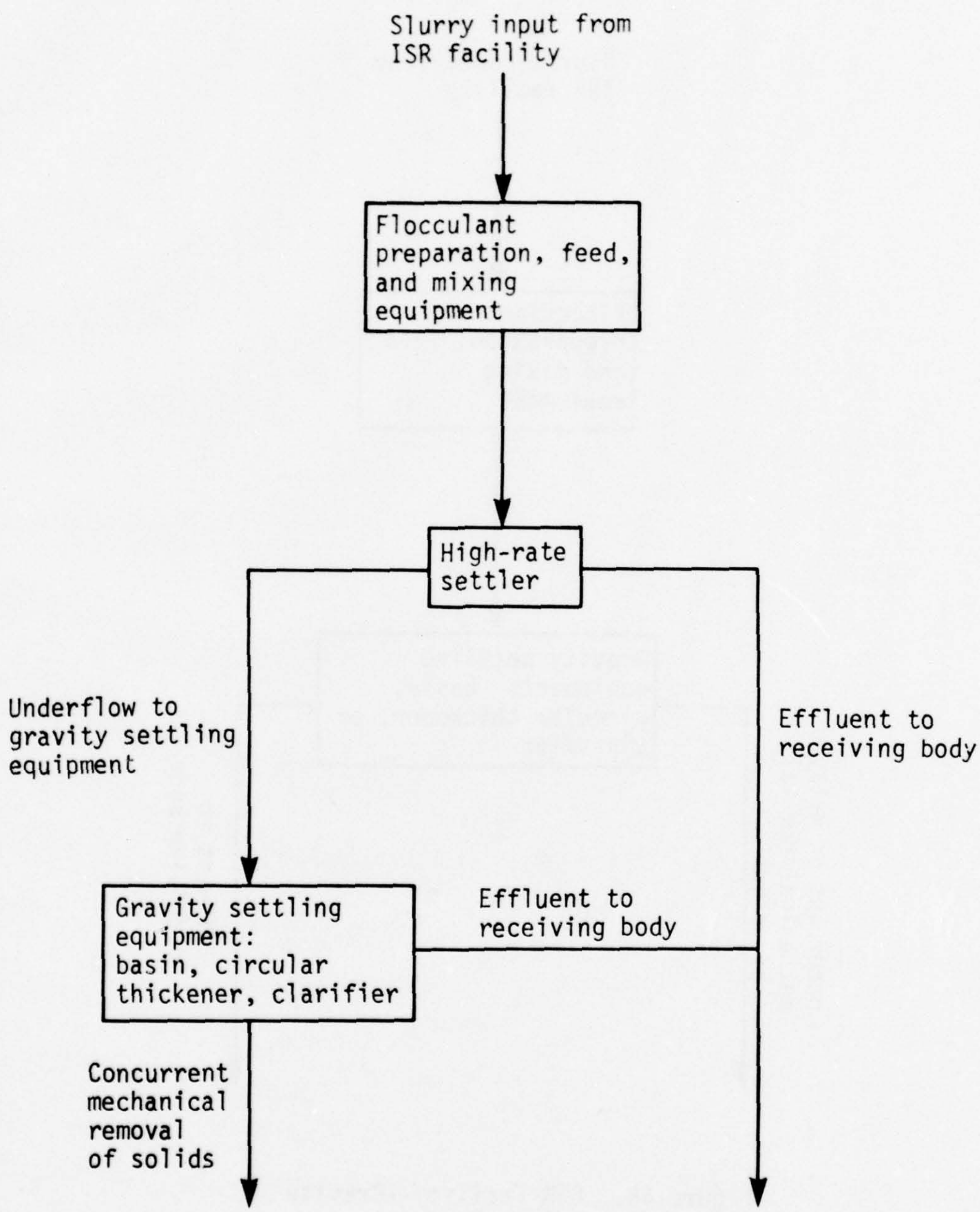

Figure 69. FSR Facility--High-Rate Settler Option

Table 24

Unacceptable Filtration Systems

Filtration System	Reason for Rejection for Use at an FSR Facility[24,37]
Squeegee (belt filter press)	10-g/l upper limit on solids loading.
Rotating wedge wire screen	Spacing of screen wires is too wide for adequate floc retention.
Slow sand filter	Low flow-through velocities require large filter areas; generally used for applications with <1-g/l solids loading; high maintenance with slurries rich in nonbiodegradable solids (typical of DM with a high clay content).
Filter press (pressure filter)	2-g/l upper limit on solids loading.
Microscreen	Usual application is on waters with <0.1-g/l solids loading; a more sophisticated unit using ultrasonics to keep the filter fabric clean can handle 20+ g/l, but the corresponding surface loading rate (0.5 gpm/ft^2) makes filter area requirements impracticable.
Electrofiltration	Impracticable because of extremely large filter areas and high costs.
Pervious dike	10-g/l maximum solids loading to prevent quick clogging, a value requiring coarser filter media and much larger filtration paths; if clogging does occur before the design life of the basin is over, remedial measures are very expensive.
Sandfill weir	2-g/l maximum solids loading.
Granular media cartridge	10-g/l influent reduces effective life of filter to one day, resulting in high capital and operating costs.

Table 24 (concluded)

Filtration System	Reason for Rejection for Use at an FSR Facility[24,37]
Diatomaceous earth filter	Exorbitant costs for supplying large quantities of filter medium consumed at the high solids loadings typical with a DM disposal operation.
Upflow and moving bed filters	1-g/l maximum solids loading.
Vacuum filter	Vacuum filters can handle solids loadings from 10-100 g/l; but at a solids loading of 20 g/l, the recommended surface loading rate is only 1 gpm/ft^2. Area needs and costs (both capital--at \$100/ft^2--and operating) are prohibitive.

backwashing and media replacement are excessive. Coarser filter media reduce clogging, but require unwieldy filtration lengths (10 metres) to provide adequate removal efficiencies; filter cleaning again is a major effort and expense.

- Large area requirements--Filtration generally requires reasonably slow percolation of the slurry through the filter medium. Therefore, large filter areas are needed to handle the high flow rates characteristic of DM disposal operations.

Should effluent standards become so stringent as to require << 1 g/l suspended solids, then filtration systems will serve a vital role. They would be added to the DM disposal site as a tertiary effluent polishing treatment (ISR--FSR--effluent polishing). The "FSR" facility then would serve a secondary (rather than final) treatment role, reducing the solids loading to a value (1-10 g/l) within the capability of these filtration systems.

Flocculation

250. Flocculation is more an art than science; different DM in various solids concentrations will respond differently to a given chemical flocculating agent. Thus, the normal procedure for a specific application is to supply flocculation equipment manufacturers with samples of the material to be flocculated for laboratory tests to determine the most economical chemical agent and feed rate for various slurry solids concentrations. In addition, the degree of bulking (which is a common consequence of flocculation) can be determined to aid in designing solids handling and storage facilities. We also recommend that the District review the findings of DMRP investigations specifically addressing flocculation.*

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* DMRP tasks 6B07--"Flocculation as a Means for Water-Quality Improvement from Disposal of Dredged Material in Confined Areas," and 6C04--"Assessment of Chemical Flocculants and Friction-Reducing Agents for Application in Dredging and Dredged Material Disposal."

251. The flocculation equipment can mix flocculating agent with incoming slurry in any of three ways:

- At a constant feed rate established by the "worst-case" design situation--This option results in undesirably high chemical waste and operating costs if slurry flow rates vary significantly from the design value. For example, if the ISR basin's overflow is cut off, but the ISR facility's secondary dredge/secondary basin continues to function, then the FSR facility's inflow rate drops to only 2000 gpm (assuming a Mud Cat dredge is used). A feed rate set for a "worst-case" design value of, say, 16,000 gpm obviously would be extremely wasteful.

- At a feed rate corresponding to the slurry flow rate, but fixed with regard to the "worst-case" solids loading--This system greatly reduces the chemical waste and costs associated with the first option and generally will perform in a satisfactory manner at a reasonable cost.*

- At a feed rate varying with both slurry flow rate and solids concentration--This system would include a station to monitor the influent rate and solids loading and to adjust the flocculant feed rate accordingly. This system appears to present an opportunity to reduce chemical waste and operating costs below those of the second option.

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* This feed procedure is similar to that used in tests conducted by the Dow Chemical Company for the Buffalo District.[24] In these tests, 8 mg/l of Purifloc C-31 was used on slurries with 0.4 to 20 g/l suspended solids at a unit cost of $5/1000 cubic metres of treated slurry. In the footnote to Paragraph 222, this was shown to be equivalent to $0.035/cy of in situ DM if the slurry as it originally enters the disposal site has a solids concentration of 10 percent. When the primary dredge encounters material coarser than the design gradation, the ISR facility will retain a higher proportion of the solids, resulting in a lower solids loading entering the FSR facility. In this case, the $0.035/cy figure still holds because the flocculant feed rate and DM dredging rate remain unchanged. If, however, the lower solids loading in the FSR facility's influent results instead from a lower original solids concentration in the slurry as it first enters the disposal site, then the cost per cy of in situ DM is greater. For instance, if the influent solids concentration in Paragraph 222's example drops to 5 percent instead of maintaining the design value of 10 percent, the solids loading at the FSR facility drops from 20 g/l to slightly less than 10 g/l. If the flocculant feed rate is not changed from 8 mg/l, the cost per cy of in situ DM becomes $0.071 because, although the same quantity of chemical is being used, the volumetric dredging rate is roughly half the design value. Still, the $0.071/cy figure is not prohibitively high. Thus, this feed rate system is a valid option.

However, the Dow Chemical Company tests referenced in the footnote to the second option also found that "water with high suspended solids loads (about 20 g/l) was often easier to clarify than water with much lower concentrations (about 0.4 g/l)."[24] The poorer clarification was attributed to a decrease in aggregation brought about by a reduced incidence of particle encounters. Since a lower solids loading promotes less effective flocculation to begin with, a reduction in flocculant could be additionally counterproductive. Thus, with regard to use of this third system, the District should heed the recommendations of flocculating equipment manufacturers who have conducted laboratory tests on samples of the DM.

Conventional Gravity Settling Equipment

252. A variety of "conventional" gravity settling equipment (some with integral flocculant feed equipment) is available, including clarifiers and circular thickeners if a small surface area is adequate, and a diked settling basin if a large surface area is required. The surface area can be determined by the design procedures discussed earlier in this chapter relative to the ISR facility.

The needed inputs are:

- "Worst-case" slurry flow rate (maximum flow).
- "Worst-case" solids loading (given by the design effluent value of the ISR facility or, if the ISR facility's prime function is to produce a clean, fine-grained material, the resulting solids concentration).
- Applicable effluent standard for suspended solids discharged into the selected receiving body.
- "Worst-case" gradation curve of the floc (finest).
- "Worst-case" specific gravity of the floc (smallest).

With these inputs, the design steps are:

• Adjust Equation 6 for the specific gravity of the floc.*

• Use Equation 2 to determine what portion of the suspended matter must be retained by the FSR facility.

• Find the necessary surface area via the trial-and-error method demonstrated in Table 20.

• Select appropriate equipment on the basis of capital and operating costs.

253. Unfortunately, two of the necessary inputs are not readily apparent--the gradation curve and specific gravity of the floc.** Laboratory analysis on the material to be flocculated is the most reliable way to determine these two inputs. Flocculation equipment manufacturers should be able to provide the District with these inputs as part of their tests to determine the most economical chemical, feed rate, etc.

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* Equation 6 may be written:

$$P = 1 - [1 + .0007934(SG - 1)D^2/(Q/A)]^{-1}$$

where: SG = solids specific gravity
D = particle diameter, μm
Q/A = surface loading rate, gpm/ft^2

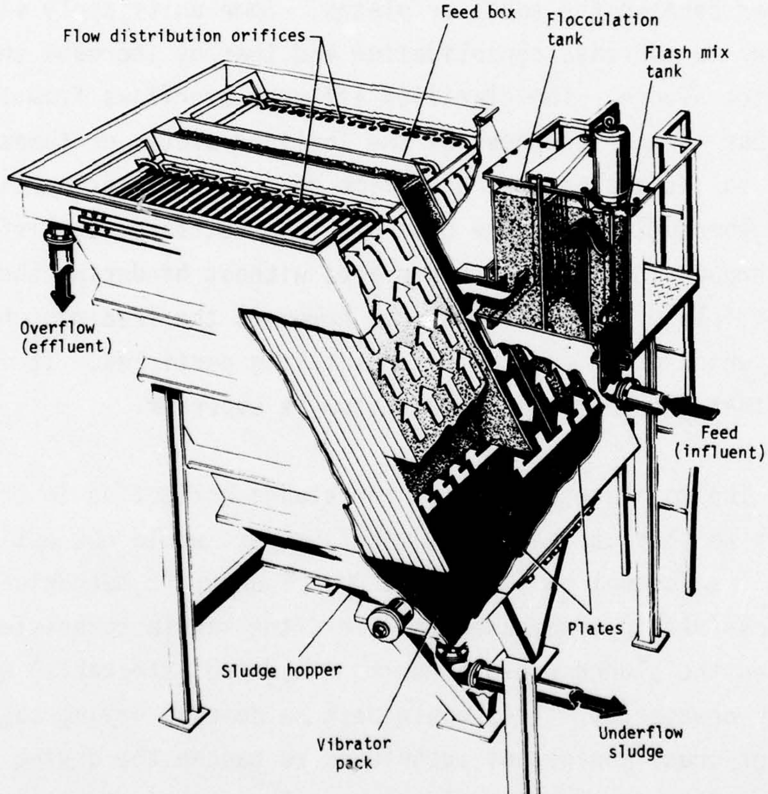
** These two inputs must be known quite accurately. Paragraph 246 pointed out the sensitivity of the surface area to gradation curve changes. Specific gravity changes can also cause large area differences. In the Dow Chemical Company tests referenced earlier, "the majority of flocs formed by treatment with Purifloc C-31 were in the range of 100 microns to 700 microns, and most of the solids had settling rates greater than 3 cm/min."[24] Flocs 100 μm in diameter settling at 3 cm/min have an effective specific gravity of only about 1.1. The large range of specific gravities (1.1 - 2.65+) means that retention values computed via Equation 6 could be considerably in error if the specific gravity is not reliable.

High-Rate Settlers

254. High-rate sedimentation equipment also relies on gravity settling to remove suspended particles; but, unlike "conventional" gravity settling equipment, high-rate settlers incorporate special features to increase the effective settling area. High-rate settlers comprise tubes or plates inclined commonly at 45-60° to the horizontal (Figure 70). Flow passes upward through the unit; particles settling under the influence of gravity move countercurrently until they drop into a hopper beneath the tubes or plates. Some units apply vibration to the hopper to increase consolidation and thereby increase the solids content of the sludge. The clarified effluent overflows from the top of the unit. Due to the steepness of the inclined plates or tubes, the movement of solids against the direction of flow promotes particle contact and agglomeration. In the case of plate settlers, the influent can be fed in through the sides of the plates without hindering the downward settling particles. In tube settlers, however, the feed must be through the bottom, which interferes with the settling particles. It is, therefore, felt that the inclined plate system is superior.

255. The moisture content of the sludge collecting in the hoppers is difficult to predict; equipment manufacturers would not estimate a value without an actual sample of the DM. Concurrent mechanical recovery is possible in some cases; however, the manufacturers felt that in most cases the sludge would be quite fluid (not stackable) and would need further dewatering. This would best be done in drying basins with the option of crust management techniques to hasten the drying process and thereby reduce the area requirements. Thus, in most cases, the primary advantage of a high-rate settler over "conventional" gravity settling equipment, namely its area economy, is at least partially lost because of the need for drying basins.

256. Present applications are with influents with no more than 7 g/l (about 0.7 percent) solids concentration. In discussions, however, equipment manufacturers did not preclude the use of plate settlers



Courtesy of Parkson Corporation

Figure 70. Inclined Plate Settler

with concentrations of 20 g/l.* Decreases in settling efficiency at the higher concentration can probably be offset by adding one or more units to the bank of settlers to divide the incoming flow further and thereby reduce flow velocities to improve settling characteristics.

257. The procedure for sizing high-rate settlers is essentially the same as that for "conventional" gravity settling equipment (see Paragraphs 252-253), except that equipment selection is made by equating the settler's "effective" settling area to the computed requirement. The same input problems exist--the lack of a gradation curve and specific gravity for the flocculated solids. Thus, the same recommendations apply: pilot studies should be conducted to provide a reliable basis for design; samples of the slurry as it would enter the settler should be provided to equipment manufacturers for testing.

Design Example

258. The following example picks up where the ISR facility example left off (Paragraphs 231-241). Items of importance that carry over are:

- 16,000 gpm flow rate (8 hours/day)
- 20 g/l influent solids concentration

The gradation curve and specific gravity of the flocs are assumed to have been supplied by flocculation equipment manufacturers after conducting laboratory tests on samples of the suspended solids as they would arrive at the FSR facility, i.e., with coarse material and most silts and clays already removed via the CMSP and ISR facilities. Figure 71 shows the

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* Solids concentrations of 10 percent by dry weight (about 100 g/l) were considered unacceptable because of the likelihood of clogging, thus precluding the possibility of feeding the disposal area's influent directly to the plate settler without passing through an ISR facility.

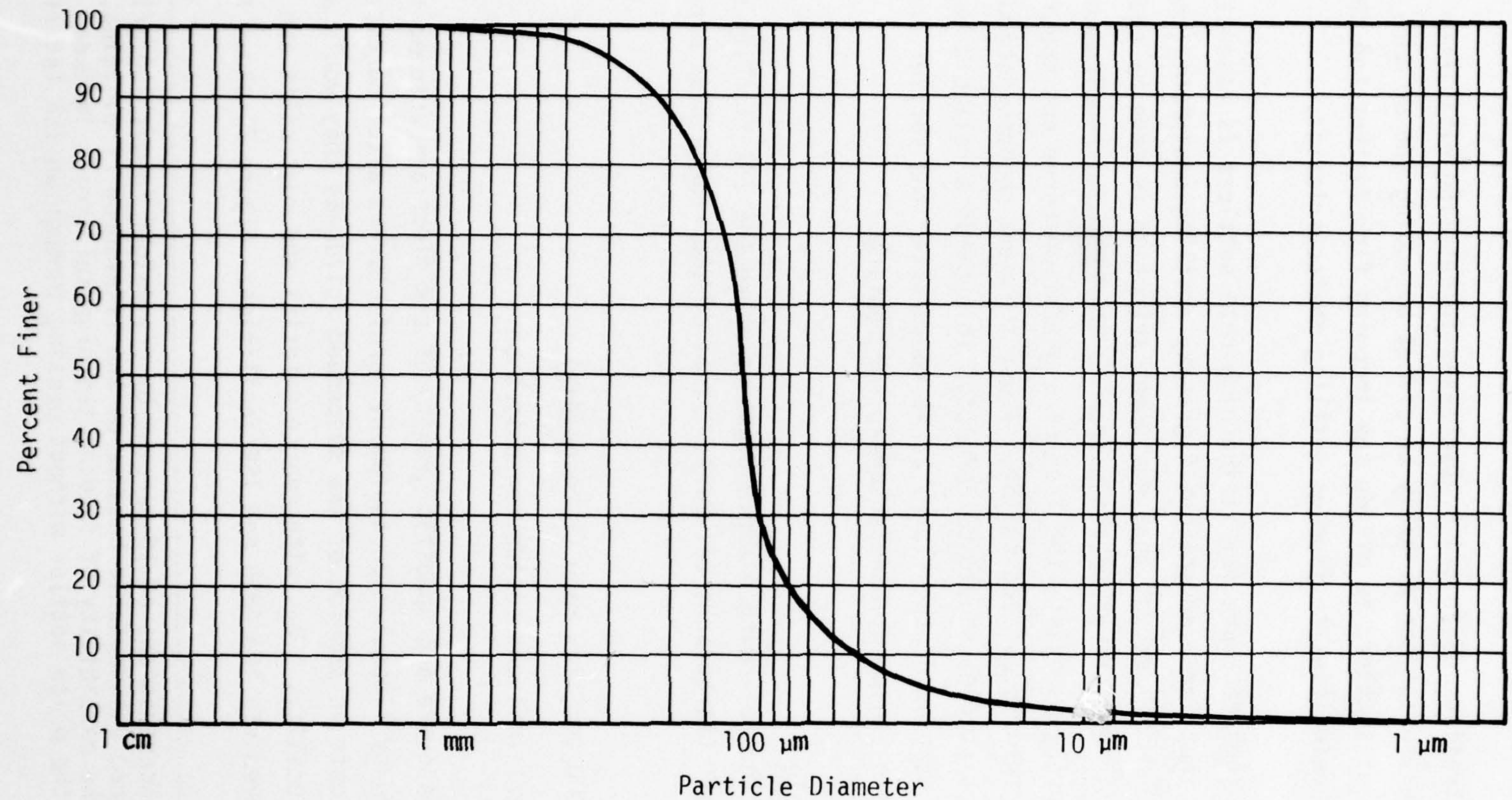

Figure 71. Assumed Gradation Curve of Flocculated Solids for Example Computation

assumed gradation curve for the flocculated material. This curve and a specific gravity of 1.1 were selected on the basis of the data in the footnote to Paragraph 253 to the effect that the majority of flocs formed with Purifloc C-31 were in the 100-to 700-μm range and had settling rates >3 cm/min.[24]

259. The surface area needed to achieve the desired degree of removal is determined as follows:

- Convert the influent solids concentration from g/l to percent by dry weight via the modified Equation 7:

$$C = 100 \times (\text{solids concentration, g/l})/[1000 + (\text{solids concentration, g/l}) \times (SG - 1)/SG]$$

For our example, 20 g/l converts to 2.0 percent.

- Compute the solids retention requirement from Equation 2 with this influent solids concentration and the applicable effluent standard for the receiving body. For this example, the effluent standard is assumed to be 2 g/l; the resulting R is 90.2 percent.

- Adjust Equation 6 for the specific gravity of the flocs (see the footnote to Paragraph 252). In this example,

$$P = 1 - [1 + .00007934\ D^2/(Q/A)]^{-1}$$

- Compute the surface area needs using the trial-and-error procedure shown in Table 20. Table 25 details the computations for this example.

260. The large surface area needed in this example, 7.5 acres, requires use of a diked settling basin.* Recovery of the settled floc

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* The 290,000-ft^2 (6.7-acre) computed value is adjusted to 7.5 acres in accordance with the cautionary recommendations in Paragraph 247. This large size is a consequence of the extremely low specific gravity of the flocs (1.1) in this example. If, instead, the specific gravity had been 1.5, the surface area needs would be only 1.5 acres (1.3 acres adjusted upward), which also would be handled cheapest by a diked settling basin, with sediment recovery either concurrently or on a delayed basis.

Table 25

Trial-and-Error Determination of Surface Area Needs for FSR Facility's Settling Equipment

Row	Item	<2*	2-30	30-60	60-90	90-150	150-200	200-400	400-600	>600	Totals
	Particle Size Range, μm	<2*	2-30	30-60	60-90	90-150	150-200	200-400	400-600	>600	Totals
	Median Particle Size, μm	--	16	45	75	120	175	300	500	600	
1	Incoming gradation curve, percent	1	4	7	12	54	9	10	1	2	100
	200,000-ft^2 surface area ($Q/A = 0.08$ gpm/ft^2										
2	Portion retained (Modified Equation 6)	0	.202	.668	.848	.935	.968	.989	.996	.997	
3	Amount retained (Row 1 x Row 2)	0	0.8	4.7	10.2	50.5	8.7	9.9	1.0	2.0	87.8
	290,000-ft^2 surface area ($Q/A = .05517$ gpm/ft^2										
2	Portion retained (Modified Equation 6)	0	.269	.744	.890	.954	.978	.992	≈1	≈1	
3	Amount retained (Row 1 x Row 2)	0	1.1	5.2	10.7	51.5	8.8	9.9	1.0	2.0	90.2

* Particles <2 μm in size are colloidal, hence nonsettling.

is best done on a delayed basis. Depending on the particular circumstances of the project, this might dictate need for a second basin to permit alternate use of one basin while sediment in the other is being dewatered preparatory to recovery by mechanical means. Crust management techniques (see Paragraphs 273-279) can be used to hasten drying.

PRELIMINARY COSTS

Nonslurry Case

261. Preliminary cost estimates for nonslurry input cases may be prepared as follows:

- Determine the mechanical handling rate via the procedures in Chapter 6, Paragraph 197.

- Estimate capital costs for any mechanical handling equipment via Figure 54.

- Compute the required size of the stockpile or containment area from the DM input projected over the life of the facility less output in the case of a reusable facility and less any volumetric reduction should densification techniques be used.

- Estimate capital costs for the containment areas based on land, dikes (if any), collector ditches, etc., via standard procedures and assumptions used by the District in costing flood control or other projects.

- O&M costs per unit of mechanical handling equipment per 24-hour work day will be $600 and $684 for a site handling less or more than 200 tph, respectively. These costs cover fuel and manpower (one operator and one laborer) per Table 13 and Paragraph 208 in Chapter 6. To this should be added a maintenance cost for the containment area equal to 0.04 percent of the capital cost.

Basin Costs

262. As is evident throughout this report, basins--primary, holding, ISR, secondary, and FSR--are common features of a DM disposal and processing site. <u>Preliminary</u> cost estimates for these basins are

shown in Figure 72 as a function of settling or containment area. This figure is based on the following assumptions:

- Dike cross section 10 feet high with 10-foot top width; inner and outer sideslopes of 1V on 1H and 1V on 2H, respectively; and a cost of $28/lft (based on $3/cy in place). The actual dike section and cost depend on foundation conditions, material available for construction purposes, type of construction, haul distances for borrow and spoil, etc.*

- Land costs of $2000/acre for lands underlying the basin and dikes. Obviously, land costs can vary considerably depending on location, with values ranging from less than $1000/acre in isolated rural areas to over $50,000 in urban areas.[38]

- Basin length-to-width ratio of 2:1. The dike length increases as this ratio increases.

- A factor of 10 percent is added to cover miscellaneous structural items, such as discharge pipes and weirs.

- A factor of 25 percent is added to cover engineering costs and a proper geotechnical program.

- Costs for basin liners are not included in Figure 72, but may be added if needed (see Paragraphs 263 and 264).

263. If leachate considerations necessitate basin liners, membrane and clay liners are favored over concrete and asphalt because of the comparatively high cost and greater susceptibility to cracking of rigid liners. Impermeable membrane liners are preferred where there is a need to stop all seepage, e.g., where possible pollution of wells supplying drinking water cannot be tolerated to any degree (see Paragraph 6). Figure 73 shows the preliminary costs for nylon reinforced

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* As noted in Paragraph 7, disposal area dikes have an unenviable reputation for poor quality and failures. It should be emphasized that disposal area dikes deserve the same care in engineering as other major earthern structures, such as levees or small dams. In Phase V, after the number of candidate disposal sites has been reduced to a very few, detailed designs and cost estimates supersede the preliminary sections and estimates of Phase III. Procedures for site investigations and dike design are discussed in Reference 7.

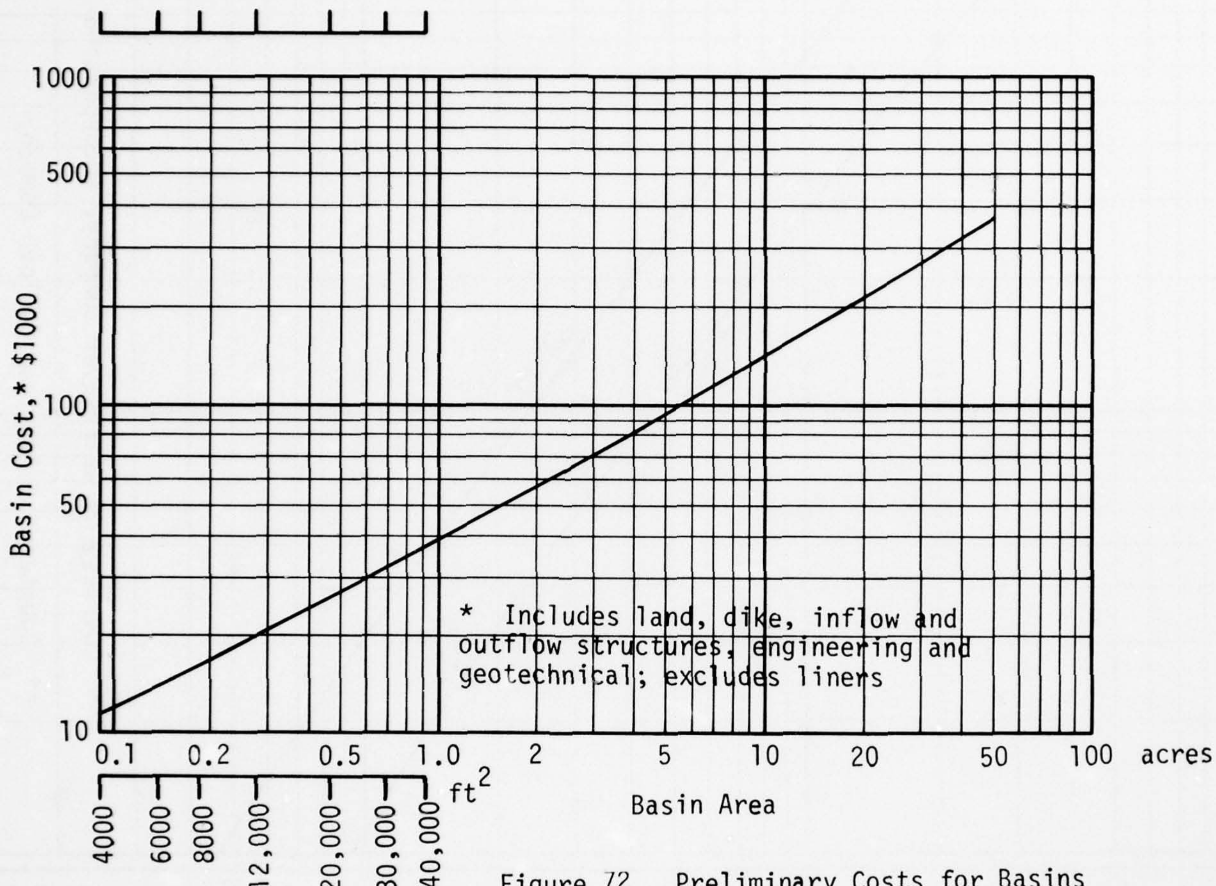

Figure 72. Preliminary Costs for Basins

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DEVELOPMENT OF PROCEDURES FOR SELECTING AND DESIGNING REUSABLE --ETC(U)
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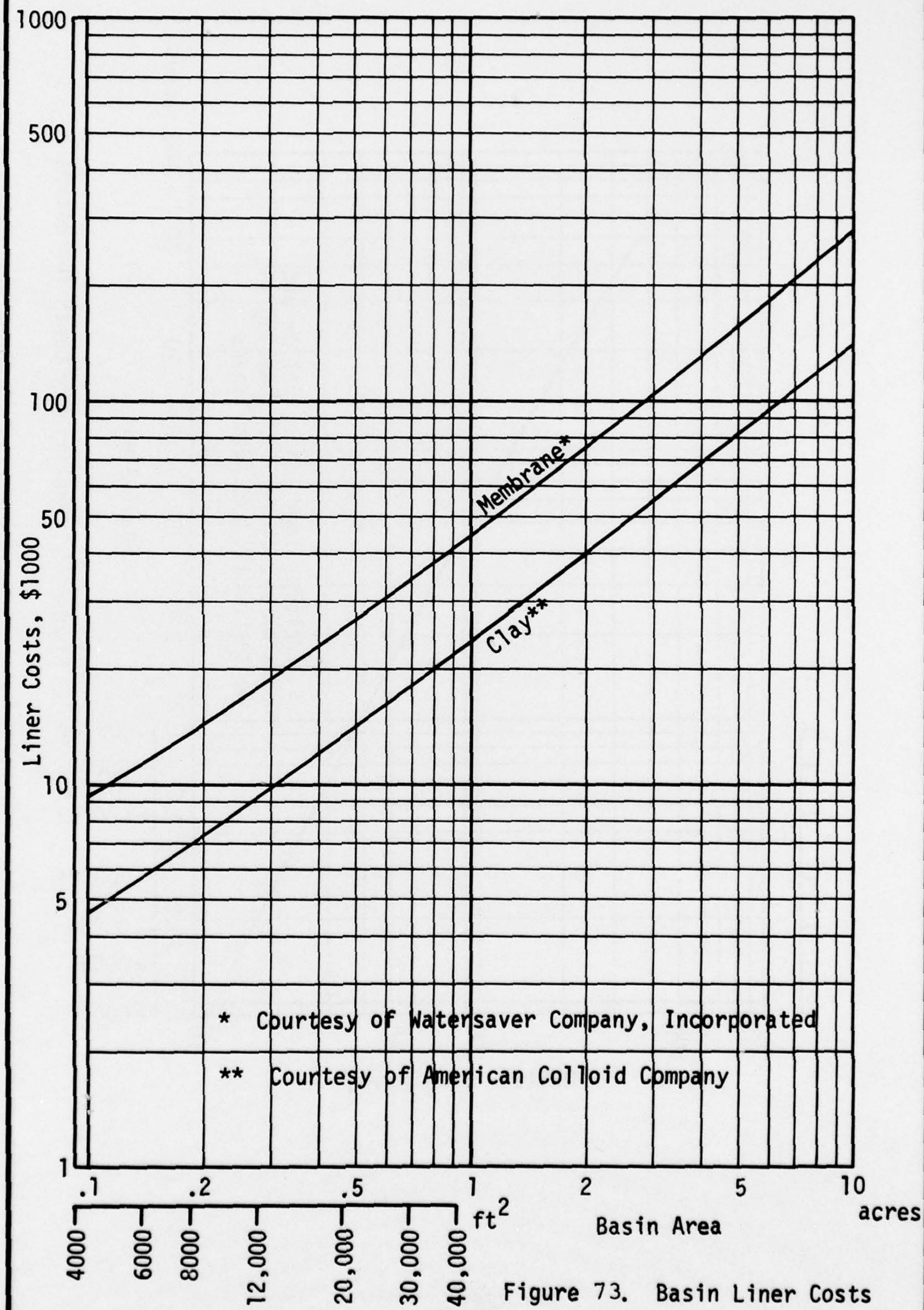

Figure 73. Basin Liner Costs

chlorinated polyethylene liners 30 mils thick. These costs include materials and installation, but exclude a protective earth or sand cover.*

264. Clays, such as bentonite, form a relatively impermeable barrier by swelling when wet to seal soil voids. A clay lining usually is applied as a mixed blanket (spread, disked, and compacted) 2-4 inches thick. Clay liners have two major advantages over membrane liners: when the seal is ruptured by ground movement or foreign object, clay particles migrate with the seepage and tend to "heal" the break. Also, clay liners are not as susceptible to degradation from exposure to sunlight or air- or waterborne chemicals. Figure 73 shows preliminary costs for clay liners including materials and installation, but excluding the cost of a 6-inch-thick protective cover of sand or gravel.

ISR Facility

265. An ISR facility is basically simple; there are few options with regard to components. In all cases, there is an ISR basin and mechanical handling equipment to recover sediment from either the ISR basin or a secondary basin (if any). A secondary dredge is used in conjunction with any secondary basins. With these few components in mind, capital costs include:

- ISR and secondary basins--Figures 72 and 73.
- Mechanical recovery equipment--Figure 54 (for draglines).
- Secondary dredge--$100,000 each, assuming Mud Cats are selected (Paragraph 204).

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* Manufacturers recommend that if an extended life is to be expected, all vinyl liners be covered by a minimum 12 inches of earth or sand on the bottom and sideslopes. In addition, in windy locations, a minimum of 8 inches of rock riprap should be placed on the earth cover at the waterline to prevent erosion from wave action.

• Drying basins-if drying basins are used to further dewater the sediment recovered from the settling basins, estimate land and dike costs.

266. Daily operating costs for the above components for a 24-hour work day include:

• Manpower--For each piece of mechanical recovery equipment or secondary dredge add $528/day (for one operator and one laborer per shift).

• Fuel--For mechanical recovery equipment add $72/day and $156/day for material handling rates of ≤200 tph and >200 tph, respectively. For secondary dredges, add $62/day.

• Maintenance--Average daily maintenance is estimated as 0.04 percent of the capital cost. (Note: to be strictly correct, land costs should be deleted from capital costs before applying this maintenance factor.)

FSR Facility

267. Preliminary capital costs for conventional gravity settling equipment are read from the appropriate cost curve after computing the required surface area of the facility:

• Clarifier--Figure 50.

• Circular thickener--Figure 51.

• Diked basin--Figures 72 and 73.

If slurry flow is split between several settling units, these units can be served by a common flocculant preparation system* and individual flow monitoring, feed control, and flocculant/slurry mixing equipment. Approximate costs for this flocculation equipment total an additional

*Flocculant preparation equipment includes storage for dry or wet chemical, mixing or dilution equipment, and associated plumbing, pumps, and tanks.

$5000, $8000, $11,000, and $14,000 for one, two, three, and four settling units, respectively. Other capital investments include drying basins (costs for land, grading, low dikes) and associated mechanical handling equipment (see Figure 54 for draglines).

268. Capital costs for plate settlers are given below in Table 26, including the flocculant/slurry mixing equipment, but excluding flocculant preparation equipment. The added costs for this latter equipment are $4000, $7000, $9500, and $12,000 to serve one, two, three, and four units, respectively. Other possible capital costs include those for drying basins and mechanical handling equipment.

Table 26

Plate Settler Capital Costs

Effective Settling Area of Unit, ft^2	Unit Cost
1150	$50,000
1700	$57,000
2500	$65,000

Note: Area requirements in excess of 2500 ft^2 necessitate multiple units.

269. Daily operating costs are shown in Table 27; chemical and maintenance costs must be added to the tabulated values to estimate total O&M costs.

Costing Example

270. This costing example is based on the ISR and FSR facility components derived in the examples worked earlier in this chapter. Assumptions other than those already noted in the examples include:

Table 27

Daily Operating Costs for FSR Equipment

Flow Rate	Flocculation Plus...			
	Conventional Gravity Settling			High-Rate Settling Via Plate Settlers
	Clarifier	Circular Thickener	Diked Basin	
Low to medium	$396	$396	0	$396
High	$528	$528	0	$528

Notes:
- All costs are based on a 24-hour work day.
- Add daily chemical costs.
- Add maintenance, estimated as 0.04 percent of the capital cost (Paragraph 209).
- Manpower costs are based on $11/hour (Paragraph 206).
- No manpower costs are shown as specific for the diked basin. Periodic inspections by personnel assigned to other tasks is adequate attention.
- Electrical costs are excluded as minor relative to labor and chemical costs.
- If mechanical handling equipment is used, say in conjunction with drying basins, add appropriate fuel costs ($72/day and $156/day for material handling rates of ≤200 tph and >200 tph, respectively, according to Paragraph 208) and manpower costs ($528/day for one operator and one laborer per shift, according to Table 13).
- Low to medium flows refer to the ≈20,000- gpm range; high flows are >30,000 gpm, although costs for flows in the 20,000-to 30,000-gpm range might be based on the high flow figures for conservative planning. $396/day assumes manpower requirements of one operator and one-half (shared) laborer per shift; $528/day assumes one operator and one laborer per shift.

- 60-day/year dredging operation at this disposal site.

- Recovery of the sediments in both the ISR and FSR facilities is on a delayed basis, with one piece of mechanical handling equipment performing both tasks.

- Solids density of the dewatered sediments in both the ISR and FSR basins is 964 g/l.

- Neither ISR nor FSR basins are lined.

271. To ensure that the sediment recovery equipment has sufficient capability and annual budget, it is sized and budgeted in accordance with the performance capabilities of the slightly oversized basins actually selected for use rather than the basin sizes computed to just meet settling requirements. In other words, in this example, design in accordance with a 10-acre rather than 8.6-acre ISR basin and a 7.5-acre rather than 6.7-acre FSR basin. The 10-acre ISR basin retains 72.6 percent (Table 21) of the incoming 275 tph, i.e., 200 tph. The 7.5-acre FSR basin retains 90.9 percent (computed via the procedure in Table 25) of the incoming 81 tph (from Figure 8 given 2.0 percent solids concentration and 16,000 gpm), i.e., 74 tph. The primary dredge operates 8 hours/day during its 60-day season at this disposal site. Thus, the ISR basin accumulates

$$96{,}000 \text{ tons/year} = 200 \text{ tph} \times 8 \text{ hours/day} \times 60 \text{ days/year; or}$$

$$118{,}200 \text{ cy/year} = (96{,}000 \text{ tons/year})/[964 \text{ g/l} \times 8.425 \times 10^{-4} (\text{t/cy})/(\text{g/l})]$$

The FSR basin accumulates 35,500 tons/year, i.e., 43,700 cy/year. These quantities fill the 10-acre ISR basin to a depth of just over 7 feet and the 7.5-acre FSR basin to less than 4 feet.

272. A sediment recovery equipment capability of 200 cyh is selected on the basis of a quick comparison of average annual costs for 100-, 200- and 300-cyh draglines. This comparison (Table 28) covers

Table 28

Comparison of Annual Costs for Draglines to Recover Sediment in Costing Example

Item	Equipment Capability, cyh 100	200	300
Capital cost (Figure 54)	$100,000	$176,000	$252,000
Days to recover sediment* from:			
- ISR basin (118,200 cy)	49.3	24.6	16.4
- FSR basin (43,700 cy)	18.2	9.1	6.1
- Total	67.5	33.7	22.5
Annual manpower costs (@ $528/day)	$ 35,600	$ 17,800	$ 11,900
Annual fuel costs (@ $72/day for 100- and 200-cyh units; @ $156/day for 300-cyh unit)	$ 4,900	$ 2,400	$ 3,500
Annual maintenance costs (@ 0.0004 x capital cost/day)	$ 2,700	$ 2,400	$ 2,300
Annual interest and amortization (@ 0.0944/year assuming 20-year life @ 7 percent interest)	$ 9,400	$ 16,600	$ 23,800
Total annual cost	$ 52,600	$ 39,200	$ 41,500

* Assuming operation 24 hours/day, 7 days/week.

Note: all annual costs rounded to nearest $100.

costs for manpower, fuel, maintenance, and interest and amortization. Table 29 summarizes the annual cost picture for the ISR and FSR facilities, including the mechanical sediment recovery equipment. These costs do not cover costs for the primary dredge, CMSP facility, stockpile areas, off-site egress and delivery, etc.

DENSIFICATION TECHNIQUES

273. Densification techniques produce the same or better degree of dewatering/consolidation as can be achieved with undisturbed natural drainage/evaporation and can achieve it in a shorter time.* Thus, densification techniques find several potential applications in DM disposal sites:

- An abandoned disposal site may be restored to active status as a non-reusable site by consolidating the DM contained therein.
- The life of an active non-reusable site may be extended by applying densification techniques to material already on site** and to subsequent deliveries.

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* Densification techniques can overcome conditions that would limit the ultimate degree of dewatering/consolidation via natural drainage--a perched water table in the disposal site; a fine gradation susceptible to pore clogging; etc. In addition, the process is hastened. Significant dewatering begins via natural drainage and evaporation as soon as the sediment's surface is exposed to the air. (Some dewatering occurs prior to decanting via consolidation induced by the weight of overlying sediment and by seepage pressures if water is able to percolate down through the sediment.) Left undisturbed, however, dewatering can take years (depending on underdrainage, vegetation, climate, and groundwater conditions) because of the characteristically poorly draining fine-grained sediments and the formation of a surface crust which cuts evaporative losses from underlying saturated sediments.

** This application is being extensively field-tested at a site in the Mobile District.[39,40] DMRP investigations of several densification techniques are based on work conducted at this same site.

Table 29

Costs for ISR and

FSR Facilities in Costing Example

Item	Cost
Capital Costs	
- 10-acre unlined ISR basin (Figure 72)	$150,000
- 7.5-acre unlined FSR basin (Figure 72)	130,000
- Flocculation equipment (Paragraph 267)	5,000
- 200-cyh mechanical handling equipment (Table 28)	176,000
- Total capital cost	$461,000
Annual Costs	
- O&M (manpower, fuel, maintenance) for mechanical handling equipment (Table 28)	$ 22,600
- ISR basin maintenance*	5,100
- FSR basin maintenance†	3,600
- Flocculation equipment maintenance[ε]	100
- Flocculant chemical[Θ]	8,700
- Interest and amortization (0.0944 x $461,000)[§]	43,500
- Total	$ 83,600

* 0.0004/day x $150,000 x 84.6 days (60 days of primary dredge operation plus 24.6 days of sediment recovery)

† 0.0004/day x $130,000 x 69.1 days (60 days plus 9.1 days)

ε 0.0004/day x $5000 x 60 days

Θ Computing per the footnote to Paragraph 222, assuming Purifloc C-31 is used at a cost of $5/1000 m^3 of slurry:

$145/day = $5/1000 m^3 x 16,000 gpm x 1 cfs/448.83 gpm x 8 hours/day x 3600 sec/hour x m^3/35.32 cf

$145/day x 60 days/annum = $8700

§ Assuming a 20-year life at 7 percent interest (factor 0.0944).

• Active and abandoned non-reusable disposal sites may be converted to reusable sites either by consolidating on-site material to produce a suitable foundation and restore storage volume or by dewatering this material for easier recovery and use or disposal elsewhere.

274. Densification techniques are the specific subject of several DMRP investigations (Table 30) and are not presented in detail in this report. However, this section does identify various techniques which have been considered, including those used to dewater other materials (e.g., sewage sludge). The reader should examine the results of the DMRP studies as they are completed and compare the time frames and costs of the various techniques relative to the needs and budget of his specific application.

275. Table 31 categorizes various physical densification techniques, several of which are shown in Figures 74-76. At the time this report was prepared, the most up-to-date review of these techniques as applied to DM was provided by Reference 41 which concluded* that:

• The cheapest way to provide additional storage volume at a non-reusable disposal site is to raise containment area dikes; costs are less (on a per cubic yard of storage regained basis) than for any densification technique. Dike raising, however, is not always possible; nor does dike raising satisfy the enhanced dewatering needs of a reusable disposal site.

• Among densification techniques, desiccation is far cheaper than any other alternative. For example, sediments with high liquid limits (characteristic of sediments with high clay contents) can be treated by placing in thin layers and trenching at a unit cost about 30-50 percent higher than that for raising dikes. The cost for any other technique is at least 3-4 times higher than that for desiccation.

• After desiccation, densification techniques fall into the following order (listed in order of increasing cost per cubic yard of storage regained): seepage consolidation (with underdrainage layer and

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* Based on a hypothetical example assuming a poor-draining foundation requiring installation of drainage layers.

Table 30

DMRP Studies and Reports on Densification Techniques

Task No.	Study Title	WES Report
5A01	Methodology for Dredged Material Reclamation and Drainage	Contract Report D-74-5[42]
5A02	A Laboratory Study of Dredged Material Slurry Water Loss Due to Mechanical Agitation	No formal report planned
5A03	State-of-the-Art Survey and Evaluation of Current Physical, Mechanical, and Chemical Dewatering and Densification Techniques	Technical Report D-77-4[43]
5A04	A Laboratory Study to Determine the Variables that Influence the Electro-Osmotic Dewatering of Dredged Material	No formal report planned
5A05	A Laboratory Study of Aeration as a Feasible Technique for Dewatering Fine-Grained Dredged Material	Contract Report D-76-10[44]
5A06	Feasibility Study of General Crust Management as a Technique for Increasing Capacities of Dredged Material Containment Areas	NA*
5A07	Feasibility of Frost Action for Densification of Dredged Material	NA
5A08	Mobile Field Study	NA
5A09	Feasibility Study of Consolidating Fine-Grained Dredged Material with Windmill-Powered Vacuum Well Points	NA
5A10	Development of Capillary Enhancement Devices for Dewatering Fine-Grained Dredged Material	NA
5A11	Feasibility of Injecting Fine-Grained Sand Slurry into Dredged Material	No formal report planned
5A12	Acquisition of Meteorological Data for On-going Dredged Material Research Studies at Mobile Test Site	NA

* NA = Not available in published form at the time this report was written

Table 30 (Concluded)

Task No.	Study Title	WES Report
5A13	Containment Area Management as a Means of Promoting Densification of Fine-Grained Dredged Material	NA
5A14	Mechanical Stabilization of Fine-Grained Dredged Material by Periodic Mixing in of Dried Surface Crust	NA
5A15	Field Evaluation of Slurry Densification by Underdrainage Techniques	NA
5A16	Mobile District Dewatering Manual	NA
5A17	Electro-Osmotic Dewatering Field Demonstration	NA
5A18	Vegetative Dewatering Field Demonstration	NA
5A19	Development of Containment Area Sizing Methodology Considering Effects of Dredged Material Dewatering	NA
5A20	Implementation of Task 5A Technology	NA
5A21	Design Alternatives Development	NA

Table 31

Physical Densification Techniques[41]

Category	Technique
Loading	. Temporary surcharge on surface of disposal area . Temporary surcharge with vertical drains - Vertical sand drains - Kjellman cardboard drains - Geodrains . Temporary surcharge by surface ponding on plastic membrane . Surface vacuum mats
Subsurface drainage	. Underdrainage with gravity flow - Natural sand foundation - Sand layer with collector pipes placed on disposal area before placement of dredged materials . Same as above, but with partial vacuum . Seepage pressure consolidation. (Surface ponding without a surface membrane, but with underdrainage) . Internal drainage - Horizontal sand layers with collector pipes - Sand finger drains with collector pipes - Cardboard (Kjellman) drains, vertical - Geodrain and other drain strips, horizontal - Electro-osmosis - Vacuum wellpoints
Desiccation	. Surface trenching to increase desiccation depths . Vegetation . Capillary wicks . Crust management - Reworking - Removal

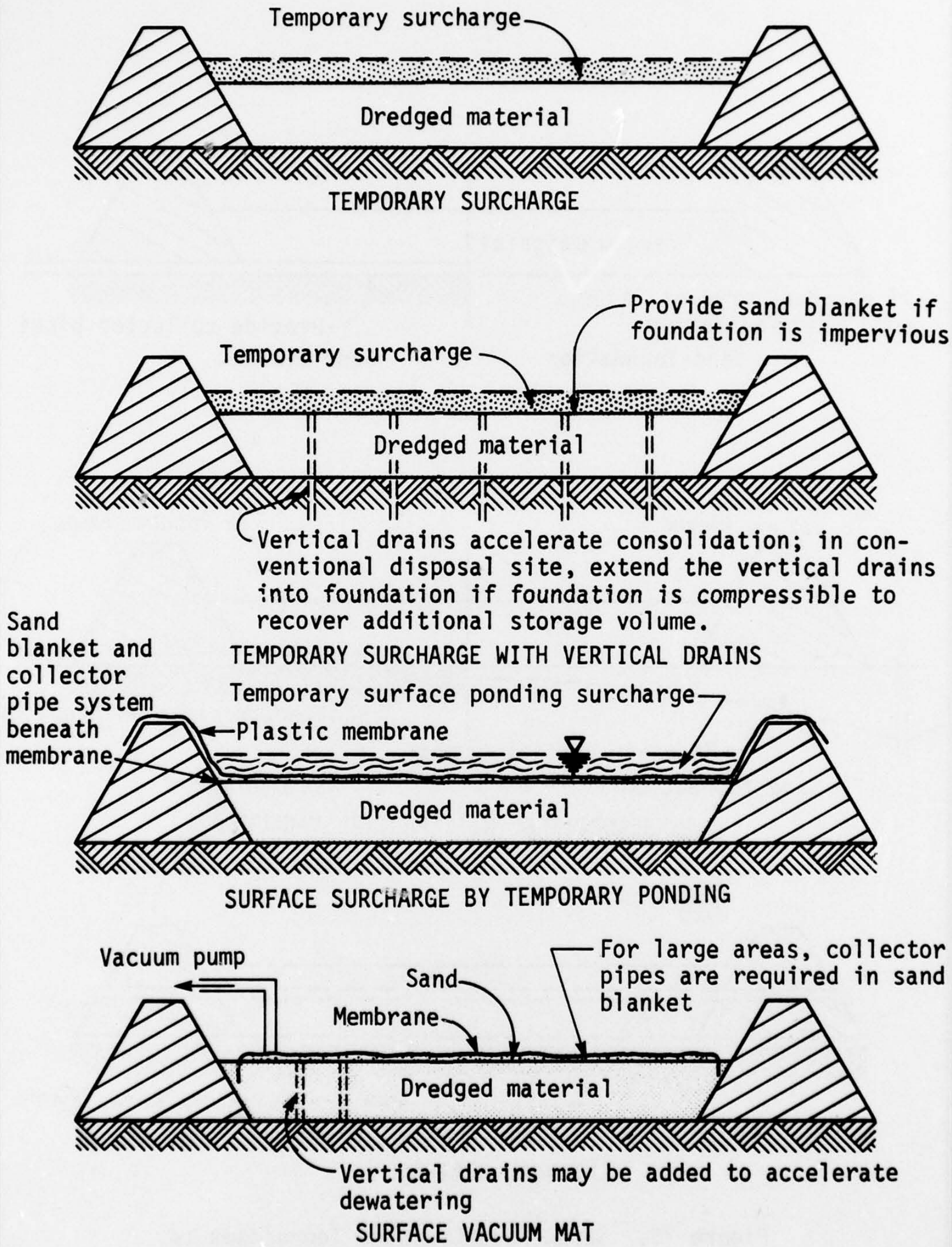

Figure 74. Loading Techniques to Increase Densification[41]

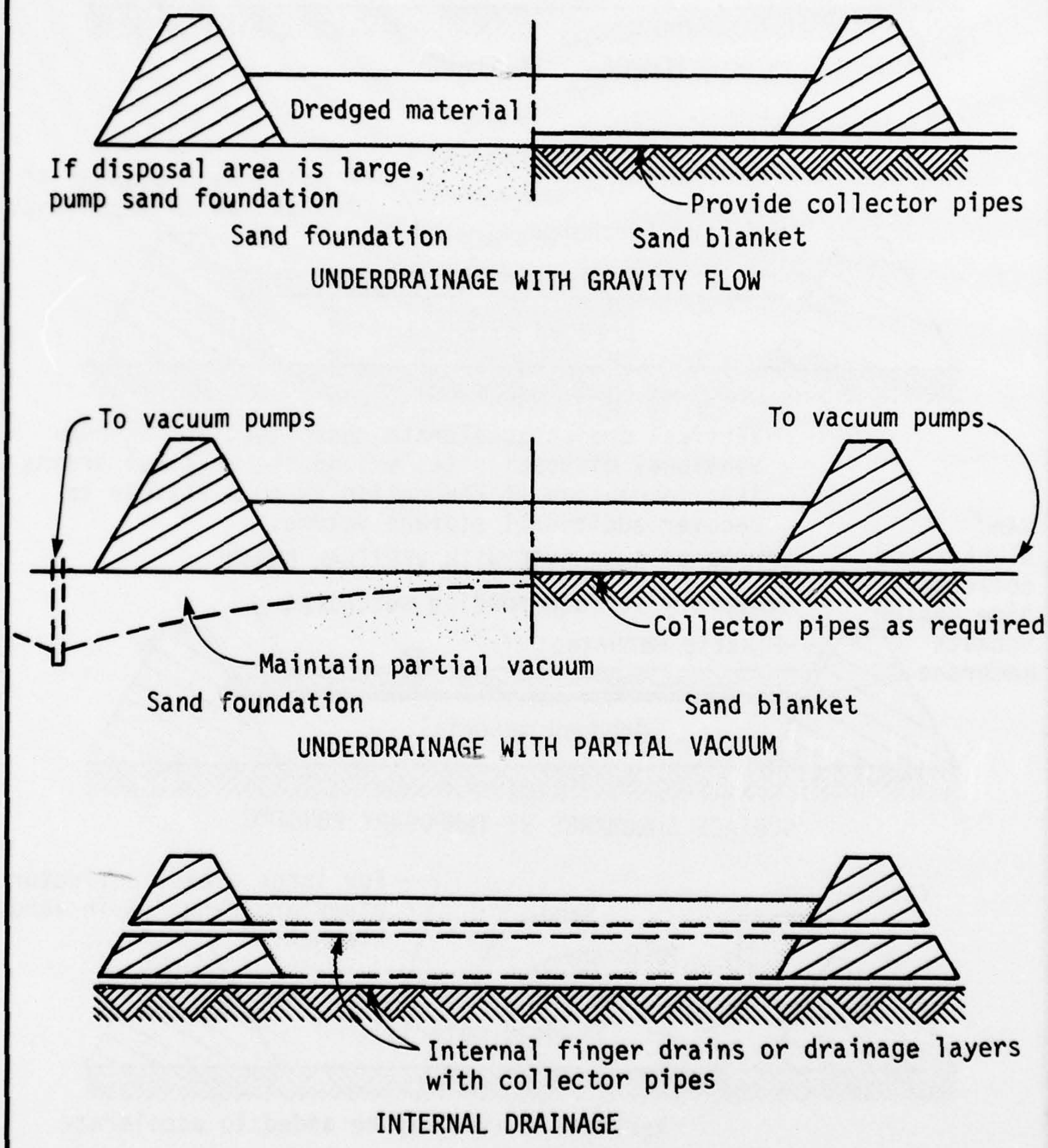

Figure 75. Subsurface Drainage Techniques to Increase Densification[41]

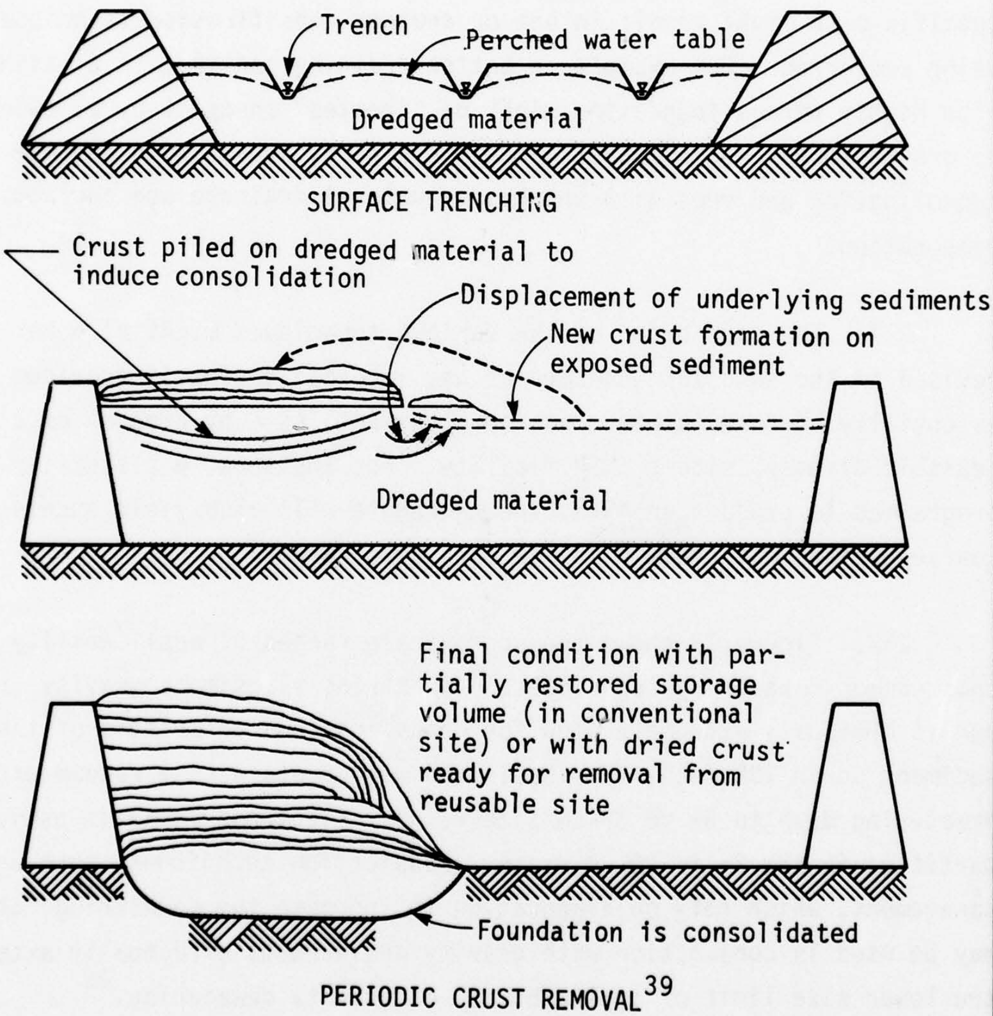

Figure 76. Desiccation Techniques to Increase Densification

collectors), underdrainage (with underdrainage layer and collectors), underdrainage with partial vacuum (with underdrainage layer and collectors), temporary surcharge techniques.

- If cost becomes secondary to rapidity of consolidation, internal drainage layers and vertical drains can be incorporated.

276. The above conclusions are not universally applicable; a specific case might result in one or another densification technique being preferred. For example, a better draining sediment in a basin with highly porous foundation might be "treated" cheapest by allowing it to gravity-drain undisturbed, which, in effect, begins with seepage pressur consolidation and ends with unassisted natural drainage and surface evaporation.

277. The cost order of the various techniques might also be revised if the sand for underdrains and internal drains is provided at essentially no cost (other than for placement) as a by-product of a reusable disposal site's CMSP facility. For instance, a classifier programmed to produce an ASTM Fine Aggregate will also yield excess coarse-grained material in one or more size ranges.

278. Figure 77 shows the approximate ranges of applicability of some common dewatering techniques. Dewatering via simple gravity drainage is obviously extremely slow for gradations characteristic of the sediment in an ISR facility. Wells and wellpoints with a vacuum extend dewatering down to 3- to 30-μm size range. Electro-osmosis is useful for particles in the 2- to 10-μm range. Dessication techniques, such as crust management, which rely on evaporation to increase the dewatering rate, may be used in conjunction with gravity drainage to effectually extend the lower size limit of applicability of gravity dewatering.[26]

279. Techniques considered, but not shown in Table 31, include the following deemed impractical for DM application by Reference 26:

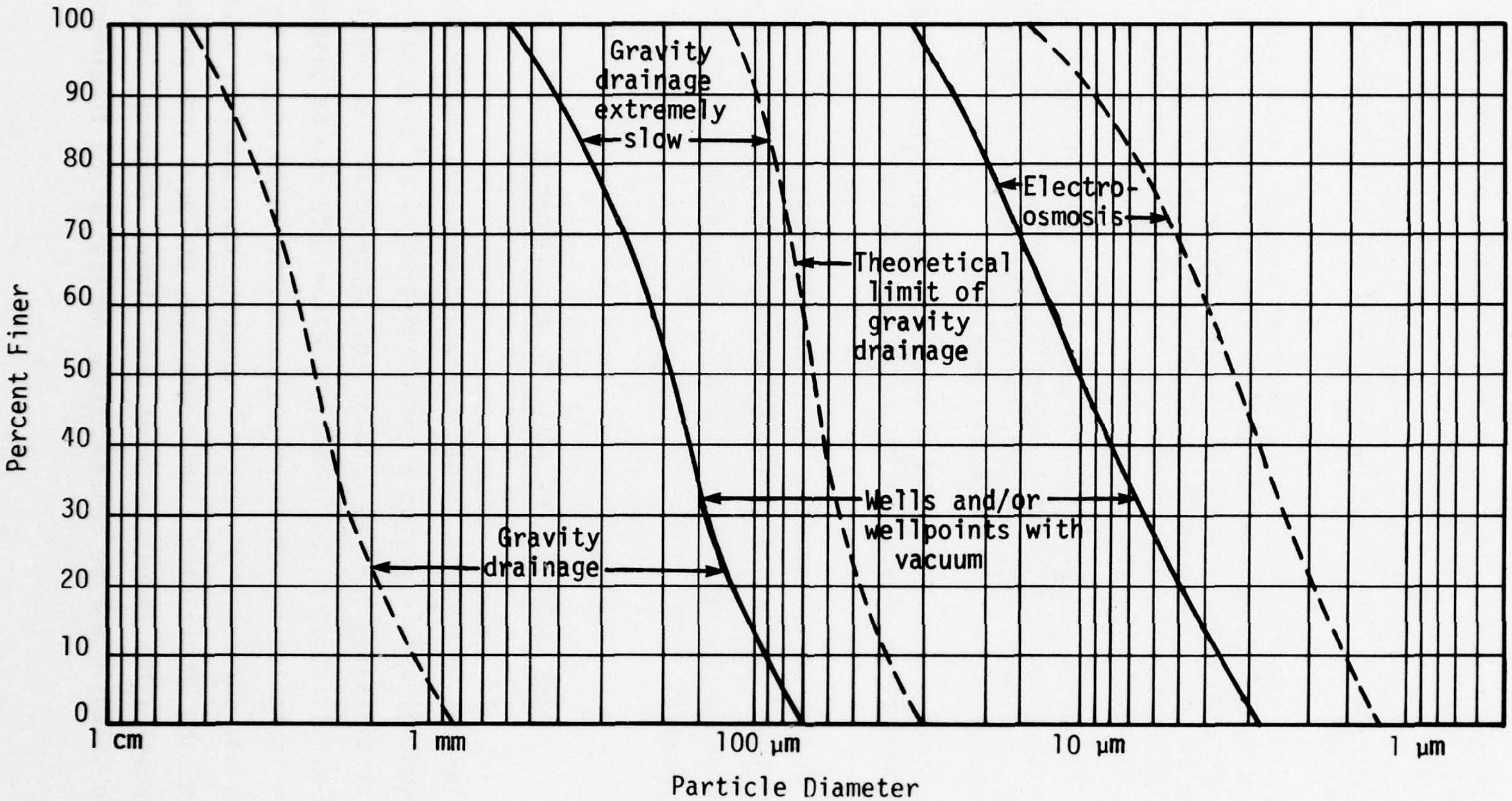

Figure 77. Dewatering Systems Applicable to Different Particle Size Ranges[26]

- Freezing--Freeze-drying was rejected because of high capital and operating costs and space requirements.

- Heat syneresis--This technique has not been applied to DM and its utility in light of the large quantities of DM to be treated is speculative at best.

- Vibration--Controlled blasting has been used to induce vibrations to dewater and consolidate unstable soils. This technique might be successful, but only on a small-scale basis with few DM gradations; furthermore, because of the large quantities of DM and because disposal sites are frequently located in environmentally- and socially-sensitive areas, blasting has extremely limited application.

- Centrifugation--Based on performances in applications to wastewater sludge, this technique cannot economically dewater to the degree desired in DM treatment. Furthermore, centrifugation is not practical on the large scale of most DM disposal operations.

- Mechanical dryers--Drying DM in heated, rotating drums is economically uncompetitive because of high operating costs.

In addition, Reference 41 investigated chemical dewatering techniques and concluded that "the potential for obtaining significant dewatering and volume reduction by addition of commonly known chemicals to dredged materials is minimal."

FINAL HANDLING OF POLLUTED END PRODUCTS

280. Various DM process stages may yield polluted end products slated for eventual use (e.g., as a soil conditioner) or disposal (either on- or off-site). Final handling of these materials may involve removal or neutralization of pollutants to allow safe use or disposal or storage in isolation of sensitive environments. With regard to polluted liquids, current DMRP research suggests that the fine solids retain most of the DM polluted load; therefore, effluent from properly designed disposal sites should be relatively clean. However, leachates from polluted solids might be contaminated, necessitating treatment

before discharge to surface waters or groundwater. A modified elutriate test (see Paragraph 61) might be used to predict leachate contamination. However, DMRP studies available at the time this report was prepared have not addressed decontamination of either solids or leachates. If problems of this nature do arise, the District is urged to consult the very latest DMRP publications for guidance.

CHAPTER 8
PHASE IV
CANDIDATE SCREENING

SCREEN MULTISITE DISPOSAL SYSTEMS

281. In Phase III (Chapters 5-7), the District in effect "disassembled" the multisite systems that survived the two-stage screening process in Phase II (Chapter 4). Each disposal site was designed and costed on a preliminary basis in accordance with its inputs, outputs, and type (reusable or non-reusable) appropriate to the role or roles it serves in one or more multisite systems. Now, in Phase IV, the District "reassembles" the multisite systems to determine composite costs and environmental/social impacts. This permits a more accurate assessment of the overall consequences of the alternative disposal schemes and the informed selection of the best one or two systems for more detailed analyses.

282. As discussed in Chapters 3 and 4, however, the sum of the costs and impacts of the individual disposal sites themselves does not reflect the overall consequences of a multisite system. Costs and impacts of ancillary "external" facilities can be equally significant and, therefore, should be treated with a similar degree of care. Consider economic factors:

- Modifications to the primary dredge-initial transport system can cost millions of dollars initially and can greatly increase O&M costs.

- Off-site transport of DM-derived products and waste materials involve large capital expenditures for spurs to tie into existing transportation systems or for supplementary transport systems should it appear that the existing systems would be overburdened. Operating costs are high.

- Annual revenues from the sale of DM-derived products can be gratifyingly high. In fiscal year 1973, the Philadelphia District alone sold some 925,000 cy of unprocessed DM "as is" in the disposal site for

over $223,000, i.e., about $0.24/cy.[18] Processed material is worth much more; sand sold in the United States for construction purposes brought in an average $1.14/ton in 1971.[26]

283. Consider environmental and social impacts of "external" facilities:

- Ingress and egress routes can have serious impacts if situated in sensitive areas.

- Off-site stockpile and waste disposal areas and some uses must be examined in light of potential problems with contaminated leachate and runoff.

- The commercial market for sand and silt materials might be adversely affected if large quantities of DM-derived products are introduced.

284. At this point in the disposal site selection process, the District can rank the systems on two bases: net costs and net environmental/social impacts. It is most unlikely that the systems will be ordered the same on both lists--a system with few adverse impacts probably achieves this distinction at the expense of higher costs and vice versa. There are various methods to select the "best" (read best compromise) system in this type of situation; the District likely has established some policy for use in flood control and navigation studies. Figure 78 illustrates one such method. Each multisite system is plotted according to its net costs and impacts.* By adopting increasingly

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* The obvious difficulties with this and similar such methods are:

- Finding a common denominator for various types of positive and negative impacts--land saved in the long run via reusable sites, acres of marsh created, cy of sand provided for beach nourishment, acres of wetlands and number of trees lost for disposal site and ingress/egress construction, number of homes suffering aesthetic degradation, businesses adversely affected by competition for sand and fill market.

- Establishing an equitable trade-off relationship between environmental/social impacts and annual costs. This is always a dilemma for the planner--setting dollar values on aesthetics, wildlife habitat, etc.

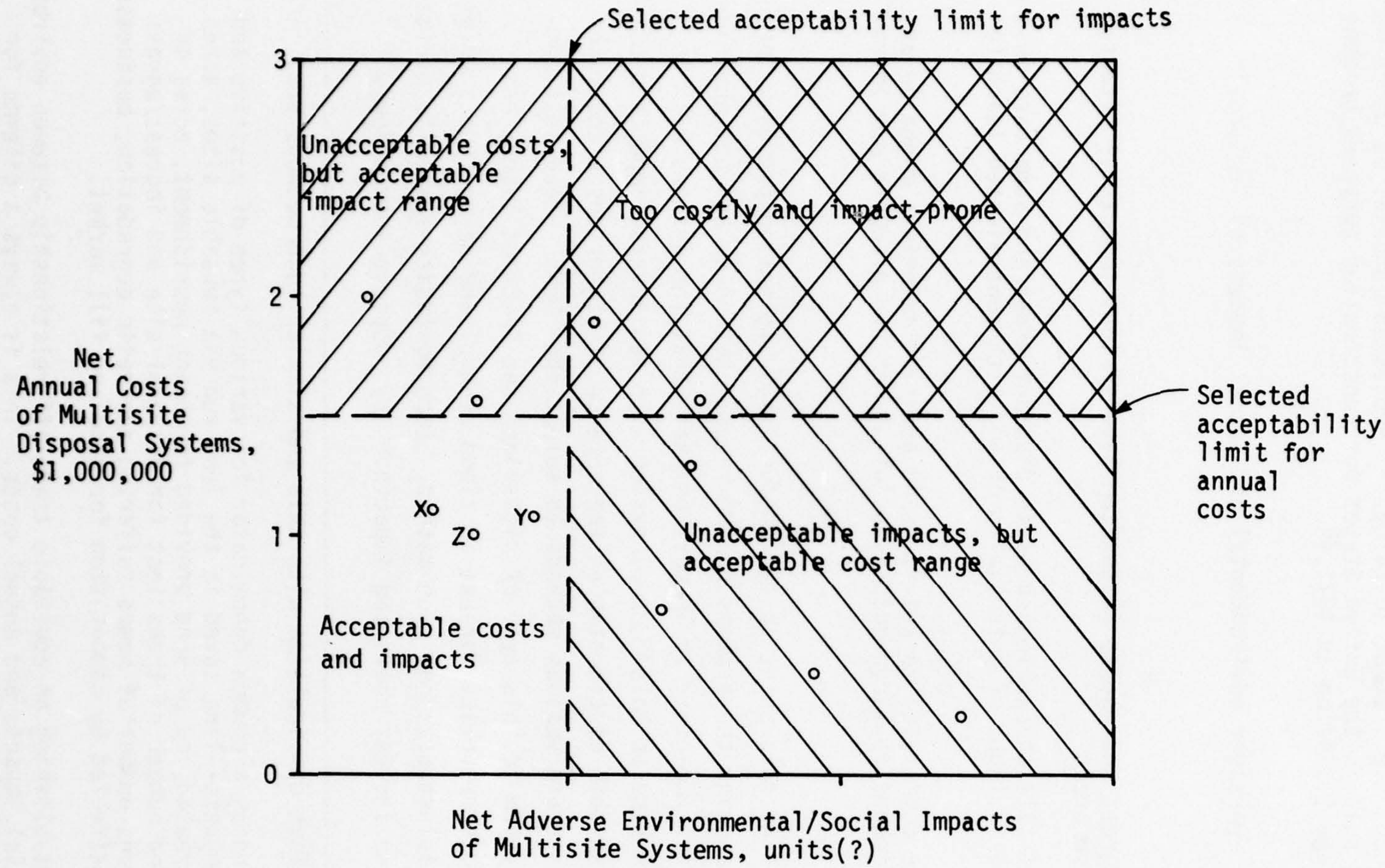

Figure 78. Aid to Selecting "Best" Multisite Disposal Systems

stringent cost and impact limits (see Figure 78), the more costly and impact-prone systems may be eliminated.* The few remaining systems can then be examined in a comparative manner to see if unquantifiable factors might provide some basis for choosing between them. In Figure 78, systems x, y, and z have survived the increasingly stringent requirements that have eliminated all other systems. System y incurs more impacts and costs than z, thus is less desirable. System x incurs more costs than z, but reduces impacts to a significant degree as well. In this fashion, systems x and z might be selected for further, more detailed study.

COLLECT DETAILED SITE DATA

285. Once the overall economic and environmental/social impacts are compiled for each multisite system and the best one or two systems identified on the basis of relative costs and impacts, then detailed data are collected on the disposal sites making up the best system(s). The function of these data is to permit preparation of more detailed designs and cost estimates in the next phase (Phase V). The types of data needed are fairly obvious:

- Topography--If necessary, crews can be dispatched to conduct surveys adequate for preparation of topographic maps with 1- or 2-foot contours. This is particularly important in determining quantities and costs for grading and diking settling basins.

- Foundation conditions--A few test borings might be necessary at some of the disposal sites to supplement otherwise inadequate information that might be cause for gross design errors. It is advisable, however, to conserve most of the test boring budget till after the final system selection to ensure adequate coverage of the disposal sites picked for actual use.

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* Not many of the systems will be grossly exorbitant in terms of costs or impacts; most of the obviously poor systems were screened out in Phase II. Thus, some new, more stringent limits must be adopted at this point to eliminate viable, but less desirable alternatives.

• Groundwater--Disposal sites with porous foundations will receive special attention to determine if leachate from settling basins might threaten an important aquifer.

• Environmental/social--Field surveys of flora and fauna at each disposal site can result in recommendations that reduce impacts with little or no performance impairment or additional costs. For example, the length-to-width ratio of a particular settling basin can be adjusted to minimize the loss of trees at a disposal site.

• Unit costs--The detailed costs to be developed in the next phase must be based on up-to-date, locale-specific unit costs. These costs can be determined by the District's cost estimating unit via recent local construction activities, quotations from equipment manufacturers, and contacts with individual landowners and appraisers.

As stressed in Paragraph 282, however, consideration cannot stop at the boundaries of the disposal sites; "external" factors--markets/users, transportation means and routes, waste disposal areas, borrow areas, etc.--can account for such a large share of the overall costs and impacts as to greatly influence decisions regarding disposal site locations, designs, and costs. Thus, detailed data collection must extend to cover these factors as well. For instance, the production estimates for various DM-derived materials provide reasonably accurate figures for follow-up market/user surveys to supplement those conducted in Phase I.

286. An equally important aspect of this phase is a public information program. This program might include news media releases, public meetings, and interviews with affected homeowners and businessmen. This program serves a two-fold purpose:

• To disseminate information on the dredging program, the deficiencies of present disposal practices, and the alternative multisite disposal systems being considered for implementation. The targets of this information include the business community, shipping firms, environmental groups, various transportation interests, and the general citizenry.

• To gauge the public's reaction and thereby identify those aspects of the disposal systems which are most objectionable.

CHAPTER 9

PHASE V

DETAILED DESIGNS AND COST ESTIMATES

287. The objectives and procedures of Phase V are fairly obvious. The first step is to firm-up the basic features of the remaining multisite disposal systems. The detailed data collected in Phase IV provide the basis for revisions in the preliminary designs developed in Phase III. Generally, the types of sites (reusable and non-reusable) will not change if the information used for decision-making in Phases II and III was reliable; therefore, the makeup of the disposal sites (CMSP, ISR, and FSR facilities) should remain essentially unchanged. This is not to say that major revisions will not be necessary, however. Consider the following:

- The improved foundation and groundwater data might indicate that, contrary to the preliminary design, a basin liner is needed to prevent percolation of contaminated leachate. The added cost of a liner might make high-rate settlers a more economical choice than a settling basin in the FSR facility.

- Feedback from the public information program might reveal that aesthetic treatments (landscaping, plantings) at highly visible disposal sites would foster greater public acceptance.

Possible changes to "external" factors must also be considered. For instance, ingress or egress routes might be relocated at a cost disadvantage to avoid an especially sensitive environment identified by field studies or the public information program.

288. Once these revisions are incorporated into the multisite systems, detailed designs and cost estimates can be made. There is a major distinction between the quality of designs and costs developed in this phase and those from Phase III. In this phase, <u>proper engineering</u>

and cost estimating procedures replace the earlier generalized guidelines. Dikes, for instance, must be sized and costed in accordance with foundation conditions, construction materials, heights needed for DM storage, actual length-to-width ratios, etc. in place of the assumed cross section and cost curves of Chapter 7. Items that received only cursory examination or were excluded entirely during the preliminary design and costing phase should now receive proper consideration. This is particularly true of "external" factors such as bottom-dump areas and road and rail spurs, but also applies to "on-site" features, such as handling equipment (conveyors, trucks, front-end loaders), open channels or pipes between processes, weirs, etc.

CHAPTER 10

PHASE VI

FINAL SELECTION

289. Final selection of the best multisite disposal system can be made primarily on an economic basis without significantly compromising environmental/social quality. The reason: none of the systems that has reached this point in the selection process has impacts markedly more severe than any of the other surviving candidate systems; any system with significantly worse impacts would have been rejected at an earlier stage. For economically similar systems, final selection can be made on the basis of net adverse environmental/social impacts.

290. If a limited lifetime is foreseen for any particular disposal site (characteristic of non-reusable disposal sites), the District should consider acquiring two or three of the top candidates with the idea of developing them one at a time. Early acquisition would prevent loss of prime sites to other uses in the interim before the inevitable need for more sites becomes desperate. This same thinking should apply to other consumables, e.g., waste disposal areas.

CHAPTER 11
CONCLUSIONS AND RECOMMENDATIONS

DISPOSAL SITE EVOLUTION

291. Environmental and economic pressures are providing the impetus for an evolution in confined disposal sites. The conventional site--too frequently poorly designed and operated, failure-prone, and short-lived--will eventually be replaced by properly designed and managed sites meeting all applicable water quality standards and making more efficient use of the disposal area. The ultimate successor to the conventional site is the reusable site, which boasts an indefinite lifetime and the option of producing useful by-products for sale. For situations where a reusable site is ill-suited, a non-reusable site can be used. The non-reusable site is also designed to meet effluent standards and can utilize techniques developed in the DMRP to extend its lifetime far beyond that attainable by a conventional site.

DISPOSAL SITE SELECTION

292. The inevitable evolution in disposal sites will influence the Corps' dredging program for the foreseeable future. This makes it imperative for the District to invest a considerable study effort as early as possible in preparing a comprehensive plan for dredging equipment replacements and disposal site acquisitions. The District thus will be better able to forecast appropriation needs and to avoid mistakes, such as acquiring equipment with inadequate capabilities for future dredging/disposal conditions.

293. In the past, convenience to the dreding operation has been the prime determinant in selecting a disposal site. In the future, with Corps dredging coming under close scrutiny, a number of factors must be

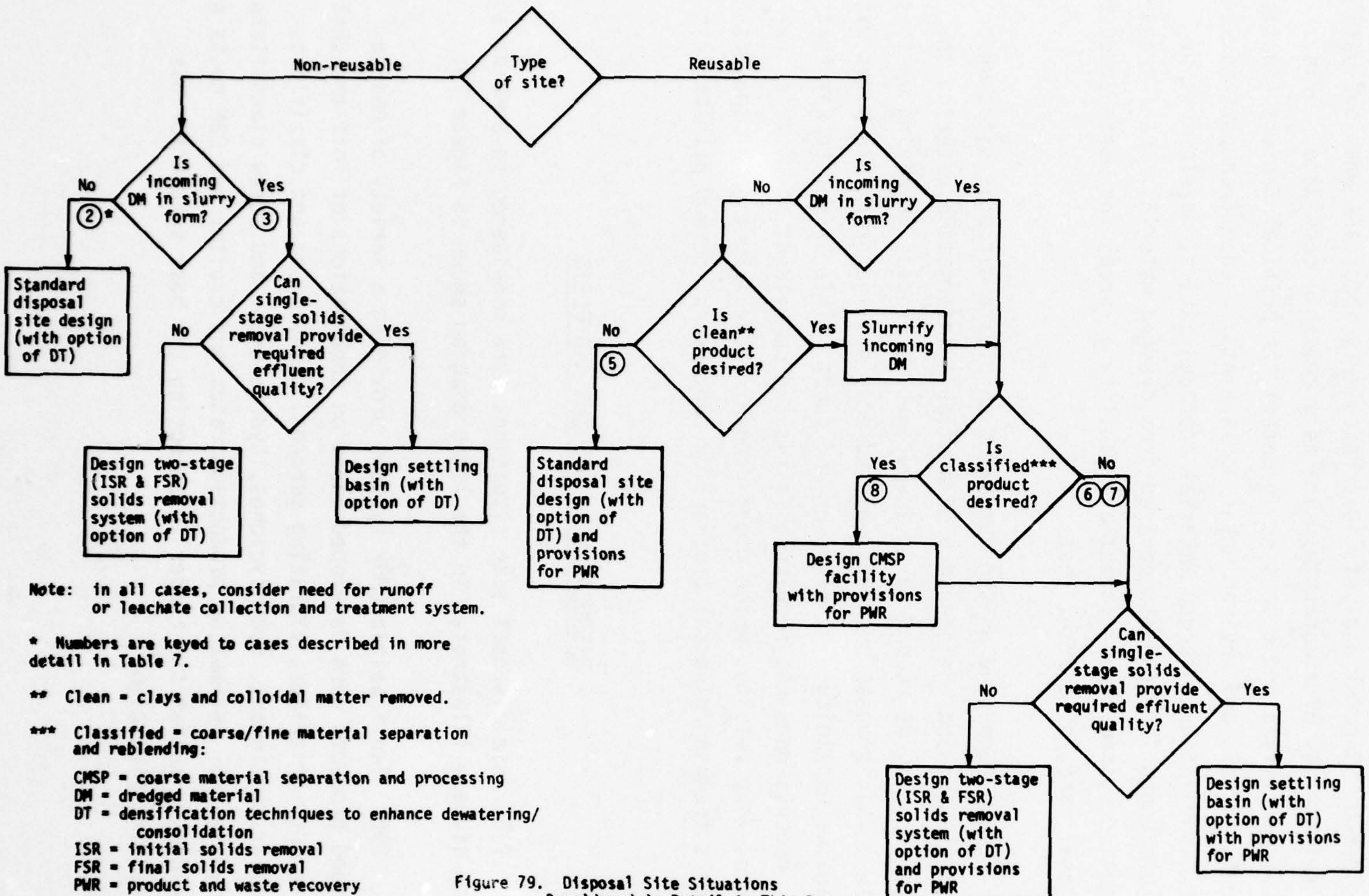
considered. Careful analysis is particularly important when evaluating the suitability of a potential site as a reusable candidate. This report identifies and discusses in detail the critical factors--institutional, social, and environmental constraints; dredge-transport equipment capabilities; dredged material characteristics; development of markets/users for products derived from dredged material; local transportation system capabilities; availability of areas for waste product disposal; and, of course, costs.

294. Depending on the number of candidate disposal sites under consideration and the adequacy of available information covering the above factors, we recommend an investigative process involving up to six phases. This process progressively screens out inappropriate sites with a minimum expenditure of manpower and funds. This is not to say that this process does not require a fair-sized commitment of District resources--the results, which might determine the direction of the District's dredging/disposal program for many years, demand nothing less.

DISPOSAL SITE DESIGNS AND COSTS

295. Six disposal site situations were considered in some detail. These six are illustrated in the logic diagram shown in Figure 79.

296. Ten feasible CMSP systems providing a variety of coarse-grained products were developed based on combinations of "off-the-shelf" equipment--grizzlies, vibrating screens, classifiers and clarifiers, circular thickeners, hydrocyclones, hydrasieves, and screw classifiers. Procedures for estimating production rates and capital and O&M costs are provided to assist the reader in selecting the best system for his particular situation.



Note: in all cases, consider need for runoff or leachate collection and treatment system.

* Numbers are keyed to cases described in more detail in Table 7.

** Clean = clays and colloidal matter removed.

*** Classified = coarse/fine material separation and reblending:

CMSP = coarse material separation and processing
DM = dredged material
DT = densification techniques to enhance dewatering/consolidation
ISR = initial solids removal
FSR = final solids removal
PWR = product and waste recovery

Figure 79. Disposal Site Situations Considered in Detail in This Report

297. Single-stage removal of solids via unassisted gravity settling was determined to provide adequate effluent quality in only about 10 percent of the cases due to the fine-grained character of the DM. Flocculation in a single-stage system was found to be unacceptably costly.

298. In a two-stage solids removal facility, the ISR (initial solids removal) system utilizes unassisted gravity settling in a standard settling basin. The ISR system reduces the solids loading to a level permitting economical flocculation in the FSR (final solids removal) system. The FSR system uses either a settling basin or high-rate settlers. Filters and other solids removal equipment were found to perform poorly under the solids loading and fine-grained conditions characteristic of DM disposal operations--either clogging quickly or passing too many particulates--and to be too costly.

299. Settling basin design should be done using a modified form of Hazen's settling theory rather than the "ideal" settling theory. Settling basin area was found to be extremely sensitive to changes in influent conditions, effluent criteria, and DM gradation curve. Care must be taken in collecting data--e.g., on dredge output and DM characteristics--to avoid grossly oversizing the settling basins (hence, unnecessarily increasing costs) or undersizing the basins (thereby causing unacceptable effluent quality).

REFERENCES

The references cited in this report and its appendices are listed below in the order in which the references were first cited. To shorten the references, the following abbreviations are employed:

WES - U.S. Army Waterways Experiment Station, Vicksburg, Mississippi

EEL - Environmental Effects Laboratory, WES

As indicated in the individual references below, some studies are still in advanced planning stages or in progress. For these reports, some changes in the title and publication date may occur; however, the information given in the reference below should still permit easy identification. Whenever the author's name was known, it was made the first entry in the reference. Particularly for reports in progress, the author's name often was not known and his organization designation had to be used.

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APPENDIX A
COMPARISON OF POSSIBLE SECONDARY DREDGES

The following table shows several measures of comparison ranging from simple dimensions to performance data. Figures A-1 to A-7 show photographs or other views of the candidate dredges. In the text of this report, the Mud Cat dredge is singled out as best fitting the role of a secondary dredge in most applications. The Mud Cat's major deficiency is its limited dredging depth (15 feet), which precludes its use in certain situations, such as redredging material from many bottom-dump areas.

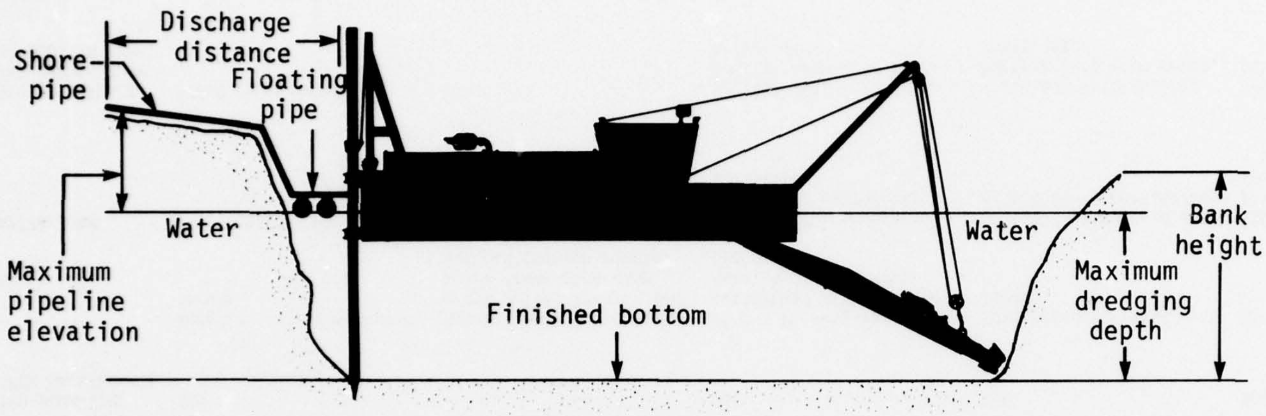
Table A-1

Comparison of Possible Secondary Dredges

MANUFACTURER:	DIXIE DREDGE CORPORATION	IHC HOLLAND	NATIONAL CAR RENTAL SYSTEM INCORPORATED	EAGLE IRON WORKS	ELLICOTT MACHINE CORPORATIO'I
MODEL:	CS-8E	AMPHIDREDGE S-170	MUD CAT MODEL MC-15	REVOLVING CUTTER-HEAD DREDGE	DRAGON SERIES 600
DIMENSIONS, L X W	28' x 11'	37.5 x 13.5'	38' x 8'	51' x 18'	44.5' x 21'
SELF-PROPELLED (SP) OR WINCH TYPE (W)	Swing winches w/cable to swing sheaves to anchors. Spuds fix dredge in operating position. 7/16"ϕ and 3/8"ϕ cables	SP by propeller. Also hydraulically operated legs for land or marsh. Winches, cables and screw anchors for positioning	Not SP. Winch & cables. $2900 for package, including screw anchors, shackles, cable etc. 5/16"ϕ cable 1000' provided ($319 value)	Not SP. Winch and cables. Requires trees and/or heavy equipment for anchors. 5/16"ϕ cable @ $.35/foot with swaged fittings.	Not SP. A 30' workboat tows and positions dredge. Swing winches, cables, and spuds provided for operations.
MANPOWER NEEDS: OPERATORS/HELPERS	1/3	1/1	1/1	1/1	1/2 (in work-boat)
SIZE (PIPE DIAMETER) COST FOR ADDITIONAL DISCHARGE PIPE	8" suction; 8" discharge $3500/100' w/pontoons and connectors $825/100' for on-shore pipe	170 mm (6-3/4") suction 150 mm (6") discharge	8" suction; 8" discharge $500/100' additional 8" pipe with couplings (aluminum pipe with ring bandlock)	8" discharge pipe ≈ $2000/100'	12" discharge pipe $8000/100' with pontoons and connectors $1500/100' on-shore pipe
DREDGING DEPTH: MAXIMUM/MINIMUM, FT.	22.5/13	16.4/0 (as long as cutter is flooded)	15/2.25	17.5/9.5	33/4
DREDGING CAPABILITY	70 cyh of in situ material	85 cyh in situ	65 cyh in situ	90 cyh in situ	350 cyh of in sity material (pumping 2000'; dredging at a 15' depth)
FLOW RATE; PUMP SIZE	2150 gpm (slurry); 120 hp	--	2000 gpm; pump driven off 175 hp diesel	3100 gpm; pump V-belt driven off 350 hp diesel	7550 gpm; pump driven through gear reducer off 840 hp diesel

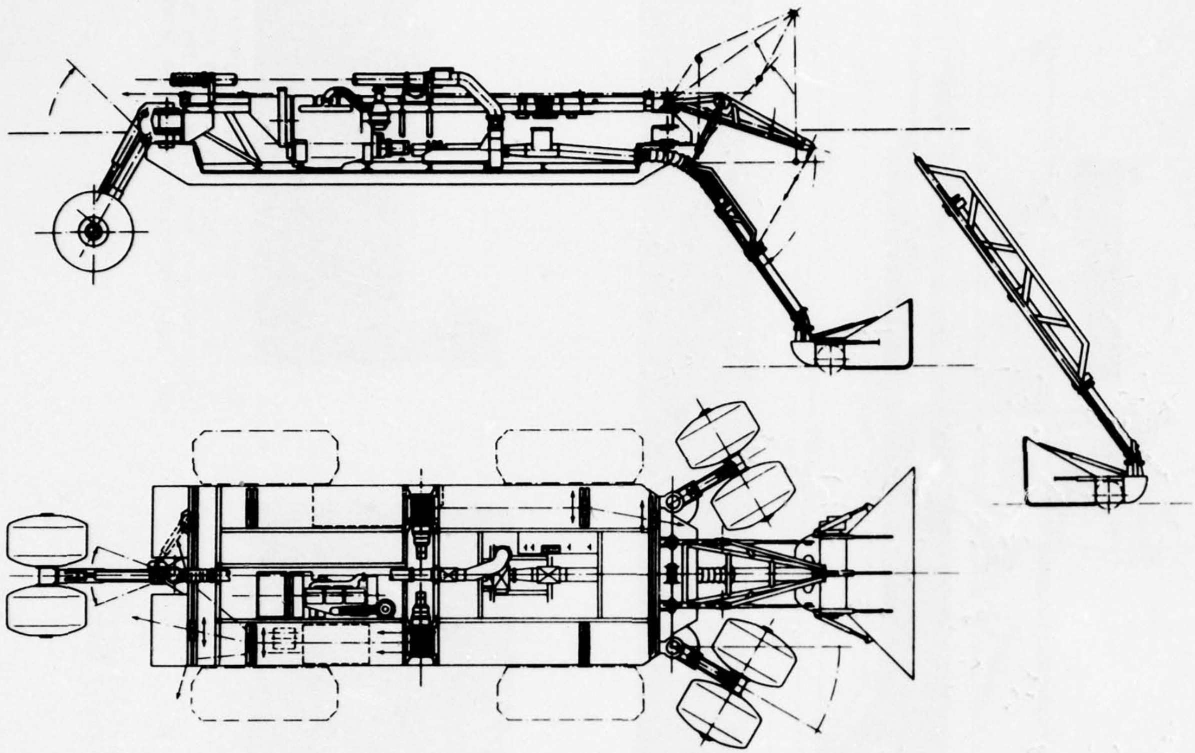
Table A-1 (Concluded)

MANUFACTURER	DIXIE DREDGE CORPORATION	IHC HOLLAND	NATIONAL CAR RENTAL SYSTEM INCORPORATED	EAGLE IRON WORKS	ELLICOTT MACHINE CORPORATION
MODEL:	CS-8E	AMPHIDREDGE S-170	MUD CAT MODEL MC-15	REVOLVING CUTTER-HEAD DREDGE	DRAGON SERIES 600
MAXIMUM DISCHARGE DISTANCE AND HEAD	1000' of 8" pipe w/static head of 10', 2150 gpm @ 13.8 fps (slurry)	3300' horizontal	2500' against 150' head	1200' horizontal	4500' for gravel @ 10' static head, 8800' for fine sand
ANTICIPATED DOWN-TIME PER YEAR FOR MAINTENANCE	20%	--	15%	10%	20%
TYPE	Rotating cutterhead with ladder	Rotating milling cutters w/hydraulically-operated space-frame pipe boom. Dustpan suction nozzle.	9" ϕ x 8"-long auger type cutterhead with boom intake; hydraulic positioners.	Rotating cutterhead with ladder	Cutterhead with ladder
COST: CAPITAL/O&M	$130,000/$67.38/hour	$113,000 for 4-legged walking model/--	$100,000 for dredge and associated equipment/ $22.57/hour	$175,000 dredge and associated equipment/$68/hour	$350,000 dredge, $115,000 pipe, $40,000 spares & accessories/ ≈ $170/hour
COST OF REPLACEMENT DREDGE PUMP (OR BOOSTER PUMP)	$7650 (pump only)	--	$21,000 skid-mounted booster pump with motor, drive, etc.	≈ $32,000 skid-mounted booster pump with motor, drive, etc.	$80,000 complete on skid-type frame
SITE PREPARATION NEEDS	Depends on particular job usage	Site preparation negligible; walks into and out of water; costs N/A	Transported on flat-bed	Transported on flat-bed	Provide roadway or ramp to water; transported knocked-down on low-boy
PLACEMENT AND REMOVAL COSTS	Costs N/A	--	$700 each	$3000 each	$10,000 each
FUEL CONSUMPTION/COST	12.5 gph/$.40/gal.	--	7 gph/$.35 to $.40/gal.	≈ 20 gph/$.40/gal.	39 gph/$.35 to $.40/gal.
TYPICAL UNIT COST FOR SOLIDS REMOVAL	$0.96/cy (based on O&M costs only)	--	$0.35/cy (O&M only); ≈ $0.57/cy (includes capital costs)	$0.70/cy (capital and O&M costs)	$0.55/cy O&M only



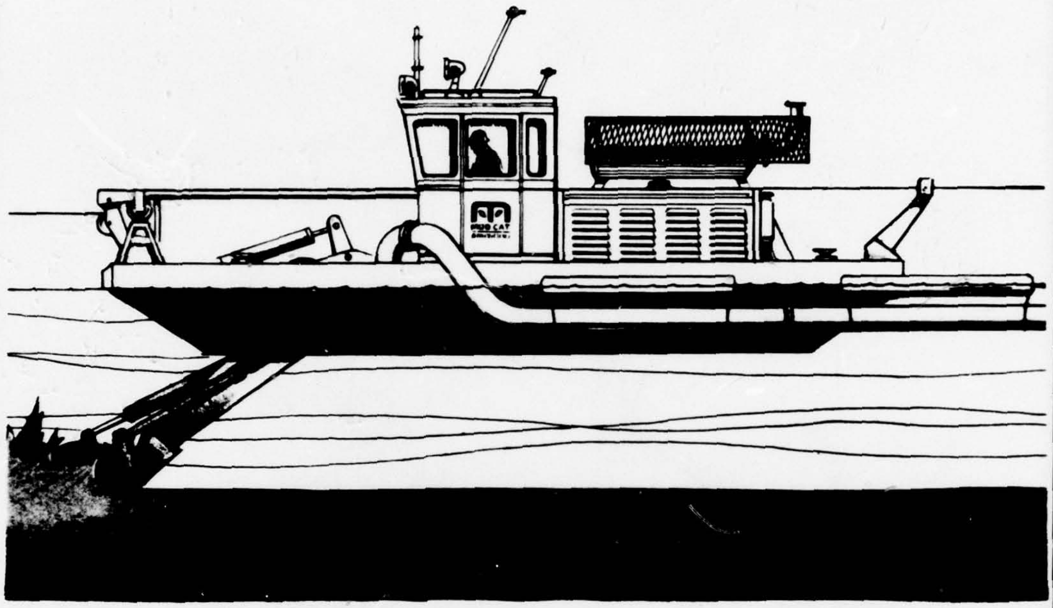
Courtesy of Dixie Dredge Corporation

Figure A-1. Dixie Cutterhead Pipeline Dredge

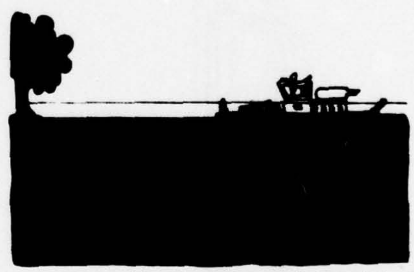


Courtesy of IHC Holland
Dredges Division

Figure A-2. IHC Holland Amphidredge S170



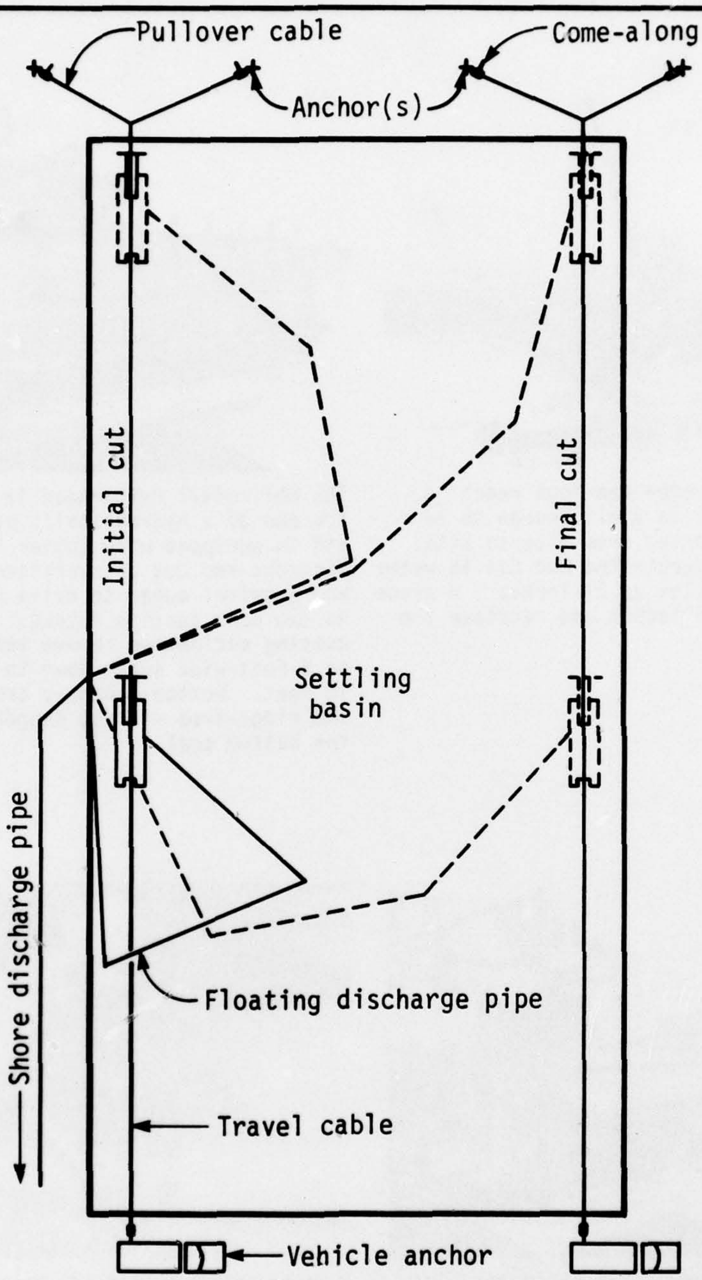
The Mud Cat clears up to 18 inches per pass.



The auger assembly is lowered hydraulically into the water where its turning action dislodges sediment and sludge from the bottom and forces the material into the intake tube.

Courtesy of Mud Cat Division,
National Car Rental System, Inc.

Figure A-3. Mud Cat Dredge

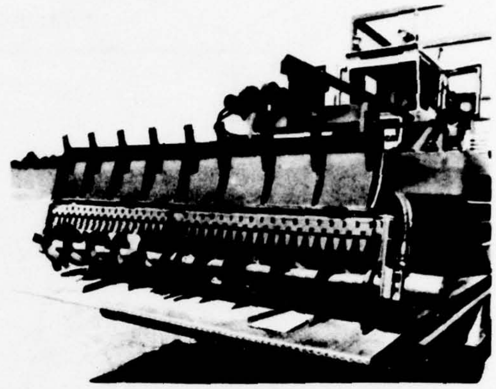


Successive pullovers (lateral movements) to position Mud Cat between the initial and final cut are not shown. To facilitate 100 percent coverage of the basin, the Mud Cat can be rotated 180° after one end of the basin has been cleared.

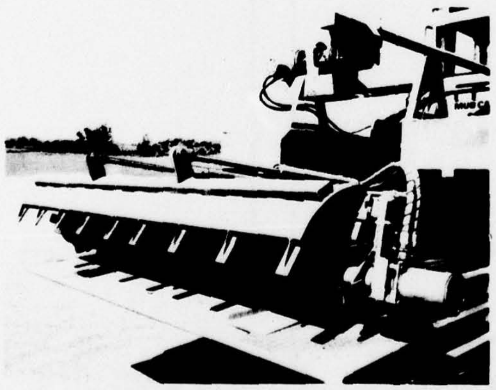
Courtesy of Mud Cat Division, National Car Rental System, Incorporated

Figure A-4. Typical Mud Cat System for Settling Basin Dredging

The Mud Cat dredge can "out reach" a drag line, yet is small enough to be easily transported from site to site. Two men can operate the Mud Cat in water depths as shallow as 27 inches. A crane can be used to launch and retrieve the Mud Cat.



The horizontal cutterhead is mounted on the end of a hydraulically operated boom and is equipped with cutter knives to dislodge and cut up oversized material and a spiral auger to drive the material to the pump suction intake. The rotating, cutting action can remove sediment in an 8-foot-wide swath down to a depth of 15 feet. Bottom contours are left even and ridge-free without danger of breaking the bottom seal.

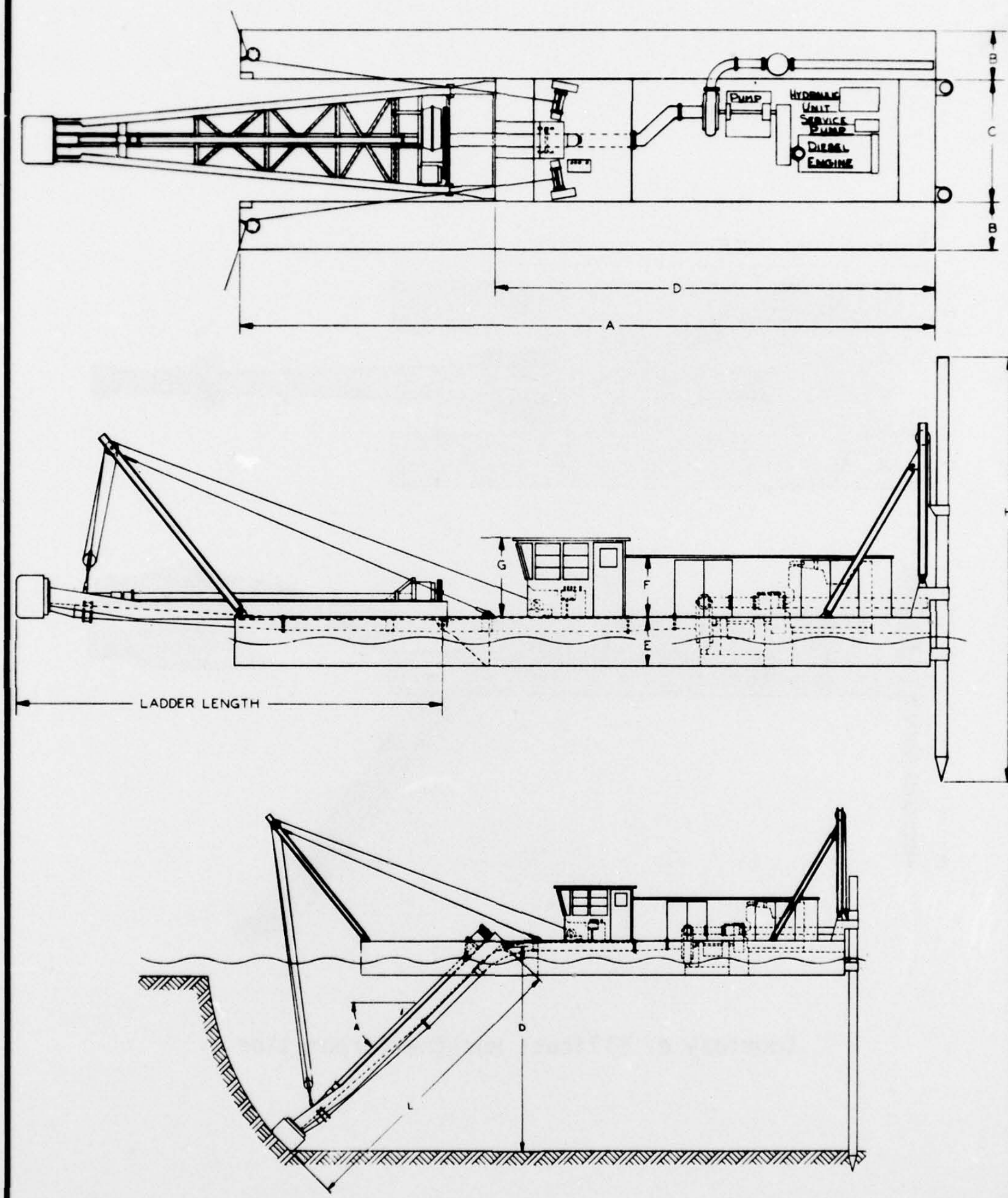


A mud shield shrouds the cutterhead, entrapping suspended material and minimizing turbidity. Teeth along the forward edge provide additional cutting capability when material protrudes above the water.

A centrifugal pump feeds the material through the discharge pipe to an area up to a half-mile away. Eight-inch diameter pipe is in 20-foot sections which can be hand-assembled over land or water. Most jobs can be set-up by two men in less than a day.

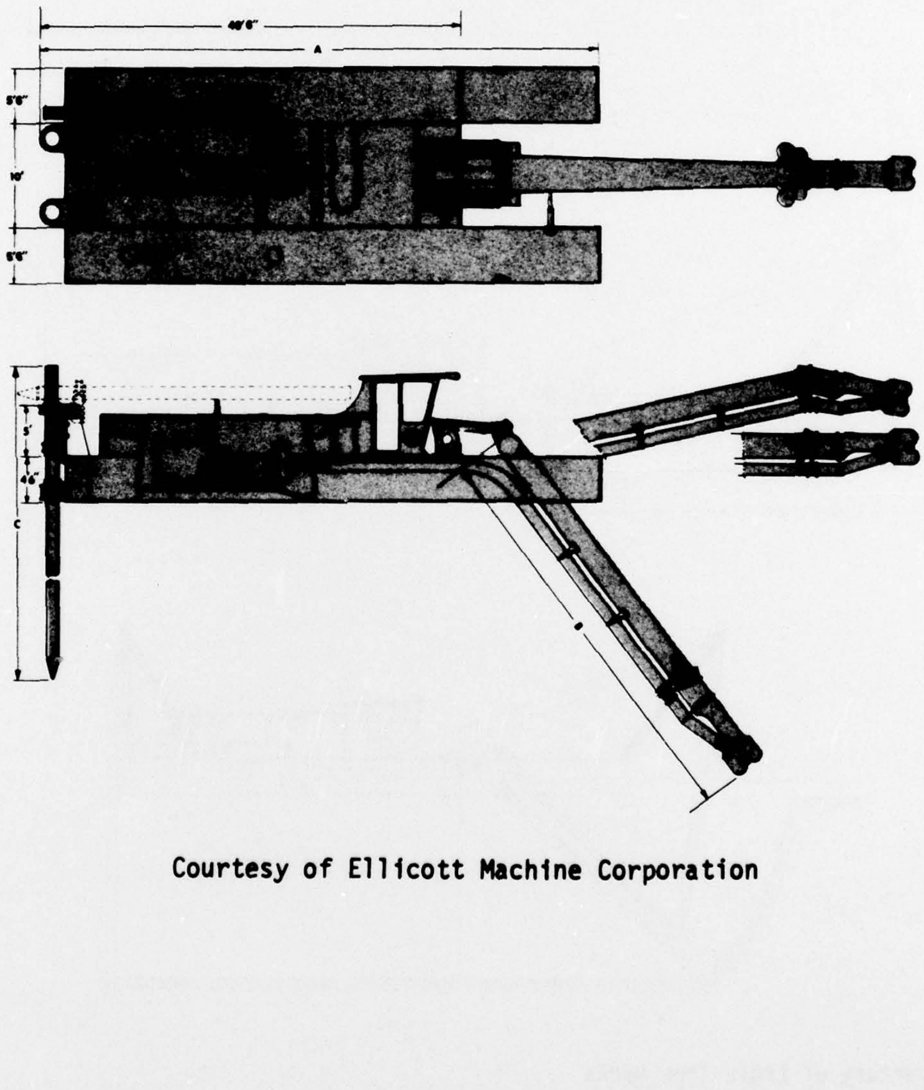
Courtesy of Mud Cat Division, National Car Rental System, Incorporated

Figure A-5. Views of Mud Cat Dredge



Courtesy of Eagle Iron Works

Figure A-6. Eagle Cutterhead Pipeline Dredge



Courtesy of Ellicott Machine Corporation

Figure A-7. Ellicott "Dragon" Series 600 Dredge

APPENDIX B

LIST OF EQUIPMENT SUPPLIERS CONTACTED

Name and Address	Equipment
IHC Holland 2 Marconistraat P.O. Box 6141 Rotterdam NETHERLANDS	Secondary Dredge
Ellicott Machine Corporation 1611 Bush Street Baltimore, Maryland 21230	Secondary Dredge
Hydro Soil Division National Car Rental System, Incorporated 5501 Green Valley Drive Bloomington, Minnesota 55437	Secondary Dredge
Pekor Iron Works P.O. Box 909 Columbus, Georgia	Hydrocyclone
Ametek 411 "D" Street South Charleston, West Virginia	Vacuum Filter
Merrick Scale Manufacturing Company 180 Autumn Street Passaic, New Jersey 07055	Weigh-Conveyor
Environmental Elements Corporation 3700 Vioppers Street P.O. Box 1318 Baltimore, Maryland 21203	Automatic Backwash Filter
Krebs Engineers 1205 Chrysler Drive Menlo Park, California 94025	Hydrocyclone

Name and Address	Equipment
Heyl and Patterson Incorporated 7 Parkway Center Pittsburgh, Pennsylvania 15220	Hydrocyclone
Bird Machine Company Incorporated South Walpole, Massachusetts 02071	Hydrocyclone
Crane Company Cochrane Division Box 191 King of Prussia, Pennsylvania	Circular Thickener, Micro-screen
Joy Manufacturing Company Denver Equipment Division 1400 17th Street Denver, Colorado 80217	Screw Classifier, Vibrating Screen, Thickener
Keene Corporation 1740 Molitor Road Aurora, Illinois 60507	Grizzly, Circular Thickener, Conveyor
General Filter Company Arrasmith Trail Ames, Iowa 50010	Circular Thickener
Parkson Corporation 5601 Northeast 14th Avenue Fort Lauderdale, Florida 33334	Plate Settler
Wemco Division of Envirotech Corporation 721 North B. Street Sacramento, California 95814	Rotary Sieve, Hydrocyclone, Screw Classifier
Telsmith Division Barber-Green Company 532 East Capitol Drive P.O. Box 723 Milwaukee, Wisconsin 53201	Vibrating Screen, Hydrocyclone, Screw Classifier

Name and Address	Equipment
Derrick Manufacturing Corporation 590 Duke Road Buffalo, New York 14225	"Derrick" System
Eagle Iron Works 129 Holcomb Avenue Des Moines, Iowa 50313	Grizzly, Screw Classifier, Secondary Dredge, Classifier, Clarifier, Hydrocyclone
C-E Bauer Division of Combustion Engineering Incorporated Springfield, Ohio 45501	Hydrasieve
Seco Screen Equipment Company Division of Hobam Incorporated 40 Anderson Road Buffalo, New York 14225	Vibrating Screen
Infilco-Degremont Incorporated Koger Executive Center Box K-7 Richmond, Virginia 23288	Grit Remover, Dewaterer, Clarifier

APPENDIX C

DEVELOPMENT AND SOURCES OF EQUATIONS USED IN REPORT

EQUATION 1 $A = 785.5\ FQ/D^2$

where A = Settling basin surface area, ft^2
F = Adjustment factor
Q = Influent rate, gpm
D = Diameter of smallest particle that must be removed, μm

This formula has been adopted from Reference 24, pp. 21-22.

$A = 2.23 \times 10^{-3}\ (Q/V_s)$

where A = Surface area of settler, ft^2
Q = Flow rate, gpm
V_s = Settling velocity, fps

But, $V_s = (g/18\nu)\ (SG-1)\ D^2$

where V_s = Settling velocity, cm/sec
g = Gravitational acceleration, 981 cm/sec^2
ν = Kinematic viscosity of water, cm^2/sec, at assumed 68° F
SG = Specific gravity of solids, assumed 2.65
D = Particle diameter, cm

Compute V_s in terms of D for assumed conditions. Convert V_s and D to fps and μm, respectively. Substitute V_s relationship in formula for A.

EQUATION 2 $R = 100\ [1 - (100/C_1 - 1)/(1000/C_2 - 1)]$

where R = Solids retention, %
C_1 = Influent solids concentration by dry weight, %
C_2 = Effluent solids concentration, g/l

This equation was adopted from Reference 26, p. 190.

EQUATION 3 $C = V \times SG / [1 + .01V (SG-1)]$

where C = Percent solids by dry weight, %
V = Percent solids by volume, %
SG = Solids specific gravity

or $C = V \times SG/M$

where M = Slurry specific gravity

Consider a 1-litre sample of slurry consisting of solids and water. By definition,

$$V = \frac{\text{Solids volume}}{\text{Total sample volume}} \times 100\% = \frac{V_{solids}}{1000cc} \times 100\%$$

Thus, $V_{solids} = 10V$

Also, by definition,

$$C = \frac{\text{Solids weight}}{\text{Solids weight + water weight}} \times 100\%$$

$$= \frac{1\ g/cc \times SG \times V_{solids}}{1\ g/cc \times SG \times V_{solids} + 1\ g/cc\ (1000cc - V_{solids})} \times 100\%$$

Eliminate 1 g/cc, substitute for V_{solids}, divide numerator and denominator by 1000 to get first form of Equation 3.

To find M, consider its definition per the 1-litre sample assumed above.

$$M = \frac{\text{Solids weight + water weight}}{\text{Weight of equal volume of water}}$$

$$= \frac{1\ g/cc \times SG \times V_{solids} + 1\ g/cc\ (1000cc - V_{solids})}{1 g/cc \times 1000cc}$$

Eliminate 1 g/cc, substitute for V_{solids}, and divide numerator and denominator by 1000 to show

$$M = 1 + .01V (SG-1)$$

EQUATION 4

$$C = \frac{100\ V_m \times SG \times (B-1000)}{(SG-1)\ [10^5 + V_m\ (B-1000)]}$$

where
- C = Percent solids by dry weight, %
- V_m = Percent of slurry volume which is material, %
- SG = Solids specific gravity
- B = Bulk density of material, g/l

Consider a 1-litre sample of slurry consisting of material (solids plus interstitial water) in a water matrix. By definition,

$$V_m = \frac{\text{Material volume}}{\text{Total sample volume}} \times 100\% = \frac{V_{mat}}{1000\ cc} \times 100\%$$

Thus, $V_{mat} = 10\ V_m$

Also by definition

$$B = \frac{\text{Weight of solids + Weight of interstitial water}}{\text{Volume of material}}$$

$$= \frac{1\ g/cc \times SG \times V_{solids} + 1\ g/cc\ (V_{mat} - V_{solids})}{V_{mat}} \times \frac{1000cc}{\text{litre}}$$

Thus, $$V_{solids} = \frac{B \times V_{mat}/1000 - V_{mat}}{SG-1}$$

Substituting for V_{mat}, $$V_{solids} = \frac{V_m\ (B-1000)}{100\ (SG-1)}$$

By definition, $$C = \frac{\text{Weight of Solids}}{\text{Weight of Sample}} \times 100\%$$

$$= 100\% \times \frac{1\ g/cc \times SG \times V_{solids}}{1\ g/cc \times SG \times V_{solids} + 1\ g/cc\ (1000cc - V_{solids})}$$

$$= \frac{100 \times SG \times V_{solids}}{1000 + V_{solids}\ (SG-1)}$$

Substituting for V_{solids}, $$C = \frac{100 \times SG \times V_m\ (B-1000)}{10^5\ (SG-1) + 100\ (SG-1) \times (SG-1)\ V_m\ (B-1000)/100(SG-1)}$$

$$= \frac{100 \times SG \times V_m\ (B-1000)}{(SG-1)[10^5 + V_m\ (B-1000)]}$$

EQUATION 5 $S = SG(B-1000)/(SG-1)$

where S = In situ solids density, g/l

SG = Solids specific gravity

B = In situ bulk density, g/l

Consider a 1-litre sample of material consisting of solids and interstitial water. By definition,

$$B = \frac{\text{Weight of solids + Weight of water}}{\text{Total volume of material}}$$

$$= \frac{1\ \text{g/cc} \times SG \times V_{solids} + 1\ \text{g/cc}\ (1000\text{cc} - V_{solids})}{1\ \text{litre}}$$

Thus, $$V_{solids} = \frac{B-1000}{SG-1}$$

Also by definition, $$S = \frac{\text{Weight of solids}}{\text{Total volume of material}}$$

$$= \frac{1\ \text{g/cc} \times SG \times V_{solids}}{1\ \text{litre}}$$

Substituting for V_{solids}, $$S = \frac{SG\ (B-1000)}{SG-1}$$

EQUATION 6 $P = 1 - [1 - 0.001325\ D^2 / (Q/A)]^{-1}$

where P = Proportion of particles of size D retained

D = Particle diameter, μm

Q/A= Surface loading rate, gpm/ft^2

This formula was adapted from Reference 24 and is valid for a solids specific gravity of 2.67 and water temperature of 68° F.

EQUATION 7 Solids concentration (g/l)= 1000 C/ [100-C (SG-1)/ SG]

where C = Percent solids by dry weight, %

SG= Solids specific gravity

Consider a 1-litre sample of slurry consisting of solids in a water matrix. By definition,

$$C = \frac{\text{Weight of solids}}{\text{Weight of solids + Weight of water}} \times 100\%$$

$$= \frac{1\text{ g/cc} \times SG \times V_{solids}}{1\text{ g/cc} \times SG \times V_{solids} + 1\text{ g/cc}\ (1000\text{cc} - V_{solids})}$$

$$= \frac{100 \times V_{solids} \times SG}{V_{solids}\ (SG-1) + 1000}$$

Solving for V_{solids},

$$V_{solids} = \frac{1000\ C}{100\ SG - C(SG-1)}$$

Also by definition, Solids concentration

$$= \frac{\text{Weight of solids}}{\text{Volume of sample}}$$

$$= \frac{1\text{ g/l} \times SG \times V_{solids}}{1\text{ litre}}$$

Substituting for V_{solids},

Solids concentration = 1000 C / [100 - C (SG-1)/SG]

Solids Delivery Rate Equations (Figure 8, Paragraph 144)

$$SDR = 0.25Q / (100/C - 1 + 1/SG)$$

where SDR = Solids delivery rate, tph

Q = Slurry flow rate, gpm

C = Percent solids by dry weight, %

SG = Solids specific gravity

Consider a 100-gram sample of slurry.

$$\text{Weight of solids} = 100 \text{ gm} \times C/100\% = C \text{ gm}$$

$$\text{Volume of solids} = C \text{ gm} / (1 \text{ g/cc} \times SG) = C/SG \text{ cc}$$

$$\text{Weight of water} = 100 \text{ gm} - \text{Weight of solids} = 100 \text{ gm} - C \text{ gm}$$

$$\text{Volume of water} = (100 \text{ gm} - C \text{ gm}) / 1 \text{ g/cc} = (100-C) \text{ cc}$$

$$\text{Density of slurry (g/cc)} = \frac{\text{Mass of slurry}}{\text{Volume of slurry}}$$

$$= \frac{\text{Mass of Slurry}}{\text{Volume of solids} + \text{Volume of water}}$$

$$= \frac{100}{C/SG + 100 - C}$$

SDR (tph) = Slurry flow rate x Slurry density x Solids concentration by dry weight

$$= Q \text{ (gpm)} \times \frac{100}{C/SG + 100 - C} \times \frac{C(\%)}{100\%}$$

$$\times 60 \text{ min/hr} \times 8.337 \text{ lb/gal water}$$

$$\times 1 \text{ ton}/2000 \text{ lb}$$

$$= \frac{0.25\,QC}{C/SG + 100 - C}$$

Divide numerator and denominator by C,

$$SDR = \frac{0.25Q}{1/SG + 100/C - 1}$$

Solids Concentration Factor Equation (Paragraph 177)

$$SCF = C_s\ [100 + C_p\ (1/SG - 1)]\ /\ C_p\ [100 + C_s\ (1/SG - 1)]$$

where C = Percent solids by dry weight, %
SG = Solids specific gravity
Subscripts s and p refer to the secondary and primary dredges, respectively

The SCF is the proportion of slurry flow rates for the primary and secondary dredges given that both have the same solids delivery rate, i.e.,

$$\frac{(SDR)_p}{(SDR)_s} = 1$$

$$= \frac{0.25\ Q_p}{100/C_p - 1 + 1/SG} \times \frac{100/C_s - 1 + 1/SG}{0.25\ Q_s}$$

Thus,

$$SCF = Q_p/Q_s$$

$$= \frac{100/C_p - 1 + 1/SG}{100/C_s - 1 + 1/SG}$$

Multiply numerator and denominator by C_p and C_s,

$$SCF = \frac{C_s\ (100 - C_p + C_p/SG)}{C_p\ (100 - C_s + C_s/SG)}$$

$$= \frac{C_s\ [100 + C_p\ (1/SG - 1)]}{C_p\ [100 + C_s\ (1/SG - 1)]}$$

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Raster, Thomas E
Development of procedures for selecting and designing re-usable dredged material disposal sites / by Thomas E. Raster ... [et al.], Acres American Incorporated, Buffalo, N. Y. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.
298, [20] p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; D-78-22)
Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under Contract No. DACW39-75-C-0119 (DMRP Work Unit No. 5C05)
References: p. 295-298.

1. Dredged material disposal. 2. Environmental factors. 3. Waste disposal sites. I. Acres American, Inc. II. United States. Army. Corps of Engineers. III. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; D-78-22.
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